EFFECTS OF 4X4 FULL DIALLEL CROSSBREEDING OF CHICKENS ON GROWTH PRODUCTION PERFORMANCE, GENETICS AND PHENOTYPIC CHARACTERISTICS

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DEDICATION

This degree is dedicated to:

- My parents for providing sound foundation of academic life to me by sacrificing for my first diploma.
- My wife Mmagabayo and our children Kesaobaka, Makopi, Letlhogonolo, Kabelo and Ipeleng for their support and love.
- My cousin Magabayo Ruth Seabela, the loving and supportive person in the family who passed on during motor accident.

DECLARATION

I BARILENG LEONARD MOGOJE hereby declare that the thesis, which I hereby submit for the degree of PhD in Agriculture at the University of South Africa, is my own work and has not previously been submitted by me for a degree at this or any other institution.

I declare that the thesis does not contain any written work presented by other persons whether written, pictures, graphs, tables or any other information without acknowledging the source. I declare that where words from a written source have been used the words have been paraphrased and referenced. Where exact words from a source have been used have been placed inside quotation marks and referenced.

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I declare that during my study, I adhered to the Research Ethics Policy of the University of South Africa and Agricultural Research Council, received ethics approvals for the duration of my study prior to the commencement of data gathering, and have not acted outside the approval conditions.

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ACRONYMS

ANOVA – Analysis of variance

APIEC – Animal Production Improvement Ethics Committee

ARC - Agricultural Research Council

CP - Crude protein

DBH - Diameter breast height

DNA - Deoxyribonucleic Acid

EEF - Economic Efficiency Factor

FCR - Feed conversion ratio

G - Gram

GCA - General combining abilities

GLM - General linear model

GPS - Global positioning system

HV - Hybrid vigour

KG - Kilogram

LB - Lohmann Brown

LBNN - Crossbreed from Lohmann Brown and Naked neck

LBPK - Crossbreed from Lohmann Brown and Potchefstroom Koekoek

LBWL - Crossbreed from Lohmann Brown and White Leghorn

LSD - Least significant difference

MA - Maternal ability

Max - Maximum

ME - Metabolizable energy

Min - Minimum

MM - Millimetres

NN - Naked neck

NNLB - Crossbreed from Naked neck and Lohmann Brown

NNPK - Crossbreed from Naked neck and Potchefstroom Koekoek

NNWL- Crossbreed from Naked neck and White Leghorn

PK - Potchefstroom Koekoek

PKLB - Crossbreed from Potchefstroom Koekoek and Lohmann Brown

PKNN - Crossbreed from Potchefstroom Koekoek and Naked neck

PKWL - Crossbreed from Potchefstroom Koekoek and White Leghorn

SCA - Specific combining abilities

SL - Sex-linked

SPSS - Statistical Package for Social Science

SSD - Stem straight degree

WL - White Leghorn

WLLB - Crossbreed from White Leghorn and Lohmann Brown

WLNN - Crossbreed from White Leghorn and Naked neck

WLPK – Crossbreed from White Leghorn and Potchefstroom Koekoek

ABSTRACT

Poultry provide affordable animal protein products compared to other animal products in agricultural industry. The demand of organic food by world health organisation and call for discard of conventional laying cage production method led to this research study. The aim of the study was to determine how (4 x 4) full diallel crossbreeding of the Potchefstroom Koekoek (PK), Naked neck (NN), Lohmann Brown (LB) and White Leghorn (WL) had an effect on production performance, egg parameters, genetic and phenotypic characteristics of F1 crossbreed offspring. The study was conducted at the Agricultural Research Council (ARC), Livestock Production Improvement at the Irene Campus, which is situated about 25 km south of Pretoria. The (4 x 4) full diallel crossbreeding design used on four chicken breeds to produce four pure breeds, six crossbreeds and six reciprocal crosses. The total number of 352 chickens with16 treatments (2 cocks and 20 hens) used in phase 1 and 384 chickens 16 F1-treatments (3 cocks + 21 hens) used in phase 2. Data was analysed by full factorial analysis of variance (ANOVA), General Linear Model procedures and Scheffe post-hoc for multiple comparison of the means of different variable data. The outcome had shown that crossbreeding had an effect on the production performance, genetic and phenotypic characteristics. The performed F1 crossbreeds emerge from crossbreeding between the local dual-purpose PK and commercial LB chicken breeds. PKLB dominated on growth and production performance traits compared to other crossbreeds. All set null hypothesis differ significantly at ($p < 0.05$), the outcome of all five hypothesis of this study were rejected. In conclusion PKLB was the best performing F1 crossbreed, based on its best performance on growth, FCR, cost of rearing, productive, high quality safe eggshell, economic efficiency and consumer preference (brown eggshell and yolk colour).

KEY WORDS:

Growth performance, egg production, egg quality, phenotypic characteristics, crossbreeding, economic efficiency factor, General Combining Abilities, Specific Combining Abilities, hetorosis

TSHOBOKANYO

Dikgogo di neelana ka dikumo tsa poroteine ya diphologolo go tshwantshanngwa le dikumo tsa diphologolo tse dingwe mo intasetering ya temo. Tlhokego ya dijo tse di bolang mo mekgatlhong ya boitekanelo ya lefatshe le pitso ya go latlha mekgwa ya kumo ya dikgetshe tsa go beela tsa tlwaelo di ne tsa isa kwa thutong ya patlisiso eno. Maikaelelo a thuto eno ke go tlhomamisa gore tsadiso ya kgabaganyo ya dilo tse pedi kgotsa go feta go tshwantshanya kgolagano ya mofuta wa dijene le tikologo tse di tletseng tsa (4 x 4) tsa *Potchefstroom Koekoek* (PK), *Naked Neck* (NN), *Lohmann Brown* (LB) le *White Leghorn* (WL) di na le ponalo mo tiragatsong ya kumo, diparametera tsa mae, le dijene le diponagalo tsa kgolagano ya mofuta wa dijene le tikologo tsa ditsadiso tsa kgabaganyo tsa ngwana wa F1. Thuto e ne ya diragadiwa kwa Agricultural Research Council (ARC) le Tokafatso ya Kumo ya Diruiwa kwa khempaseng ya Irene, e e agilweng bokana ka 25 km jwa borwa jwa Pretoria. Ditsadiso tsa kgabaganyo tsa dilo tse pedi kgotsa go feta go tshwantshanya kgolagano ya mofuta wa dijene le tikologo tse di tletseng tsa (4 x 4) di ne tsa dirisiwa mo mefuteng ya ditsadiso tsa dikgogo go ntsha mefuta ya ditsadiso e e tletseng e mene, ditsadiso tsa kgabaganyo tse thataro le dikgabaganyo tse di tshwanang tse thataro. Palo e e tletseng ya dikgogo tse di 352 ka ditiragatso di le 16 (mekoko e le 2 le dithole di le 20) di ne tsa dirisiwa mo letlhakoreng la 1 le dikgogo di le 384 ka ditiragatso tsa F1 di le 16 (mekoko e le 3 + dithole di le 21) di ne tsa dirisiwa mo letlhakoreng la 2. Data e ne ya tshetshereganngwa ka tshetshereganyo ya dintlha tse di tletseng tsa pharologantsho (ANOVA), dikgato tsa *General Linear Model* le tshwantshanyo ya bontsintsi ya morago ga tiragalo ya Scheffe ka mekgwa ya data ya pharologantsho e e farologaneng. Ditlamorago di ne tsa bontsha gore ditsadiso tsa kgabaganyo di na le ponalo mo tiragatsong ya kumo, ga mmogo le diponagalo tsa dijene le setlhopha sa kgolagano ya mofuta wa dijene le tikologo. Go ne ga diriswa mefuta ya ditsadiso tsa kgabaganyo ya F1 tse di tlhagelelang go tswa mo ditsadisong tsa kgabaganyo magareng ga mefuta ya ditsadiso tsa dikgogo tsa PK tsa lebaka la gabedi la selegae le LB ya kgwebo. PKLB e ne ya fekeetsa metlhala ya tiragatso ya kgolo le kumo go tshwantshanngwa le mefuta ya ditsadiso tsa kgabaganyo tse dingwe. Setlhopha sotlhe sa dikakanyo tsa lefela se

farologana mo go bonagalang ka ($p < 0.05$) le ditlamorago tsa dikakanyo tse tlhano tse tsotlhe tsa thuto eno di ne tsa kganediwa. Kwa bokhutlong, PKLB e ne ya nna mofuta wa ditsadiso tsa F1 o o diragatsang go gaisa, go ikaegilwe ka tiragatso mabapi le kgolo, FCR, tshenyegelo ya go tsadisa, kumo, boleng jo bo kwa godimo jwa dikgapetla tsa mae tse di babalesegileng, bokgoni jwa ikonomi le boikgethelo jwa modirisi (dikgapetla tsa mae tse di tshetlha le mmala wa tlhae).

MAFOKO A MOTHEO:

Tiragatso ya kgolo, kumo ya mae, boleng jwa mae, diponagalo tsa kgolagano ya mofuta wa dijene le tikologo, ditsadiso tsa kgabaganyo, ntlha ya bokgoni jwa ikonomi, dikgono tse di tshwaraganyang tse di totobetseng, *heterosis*

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CHAPTER 1

1 INTRODUCTION

Indigenous chickens are kept in a traditional free range system with low inputs and result in low outputs (FAO, 2011). However, these indigenous and local chickens contribute to poultry meat and egg production in developing countries. The production of indigenous chickens, raised on outdoor-based systems with minimal negative environmental impacts remain viable option to meet international and local organic farming standards (Besbes, 2009).

Efforts to improve the performance of indigenous chickens, both with regard to their egg and meat production, have been attempted through the crossbreeding of local hens and exotic commercial cocks (FAO, 2009). The genetic resources provided by indigenous chickens form the base for research on genetic improvement and diversification of chickens during the production of new breeds (Saadey et al., 2008; FAO, 2011). Crossbreeding of indigenous and exotic breeds is one of the methods used to explore genetic variation among breeds. The main purpose of crossbreeding is to produce superior species (make use of hybrid vigour), to improve fitness, fertility traits, and to combine different characteristics of economic importance (Razuki & Al-Shaheen, 2011).

The growth in poultry is influenced by the genotype of the chickens, which is inherited from the dam or sire, nutrition, hormones, tissue specific regulatory factors and other environmental aspects (Kingori et al., 2010). Different poultry breeds have different nutrient requirements. To meet the nutritional requirements of any chicken breed, the ration formulation needs to be accurate and precise (Mbajiorgu, Ng’ambi & Norris, 2011). The performance of the chicken, in relation to economic and profitable production of eggs or meat, depends on adequate supply of nutrients in the feed-rations.

The adapted African indigenous chickens in South Africa have largely been disregarded and there are limited data available on these breeds (Grobbelaar, Sutherland & Molalakgotla, 2010). Indigenous chickens have been identified as a source for the development of adaptive free-range breeds for the production of organic products (FAO, 2009). Therefore, there is a need in South Africa to conduct research on the crossbreeding of indigenous with exotic chicken breeds, in order to see whether this will produce superior breeds and/or enhance egg production. Therefore, the present study, used 4x4 full diallel crossbreeding method to cross two indigenous breeds (Naked neck and Potchefstroom Koekoek with two exotic chicken breeds (White Leghorn and Lohmann Brown) to establish an egg-type F1 crossbreed that is able to perform with considerable economic efficiency with regard to egg production.

1.2 PROBLEM STATEMENT

Poultry farmers are facing the challenge of complying to animal welfare laws in their farms and threat of consumer perception and demand of organic food (Capuano et al., 2013; Janczak & Riber, 2015; Den Hartigh, 2016). There is an increase of scientific evidence indicating that the consumption of animal products that has some antibiotic resistant bacteria originating from animals, contribute to the formation of some resistance bacteria on human (Muzaffer, Ferda & Kemal, 2003; Castillo et al., 2008; Vondruskova et al., 2010). This resulted in increasing concerns on the effects of these pathogenic bacteria on human health that changed the consumer demands. The environmental, ethical and animal welfare issues in relation to conventional cage system for layers enforced a change in such production system. A demand for egg production that are certified “free-range” or “organic” have emerged (Besbes et al., 2007; Capuano et al., 2013; DAFF, 2015).

The common poultry farming practices across the world associated with controlled environmental housing, had allowed a greater focus on efficiency, maximising benefit per animal place and quality traits (Besbes et al., 2007). There was less focus on adaptation to local environments, disease resistance, animal welfare and exposure to semi-extensive systems. The poultry industry is facing challenges of a change to product trend that is moving towards free-range poultry products and certified organic products (Capuano et al., 2013; Singh & Cowieson, 2013). There is a need for South Africa to develop or find productive layer breeds that met consumers' organic perceptions. These breeds need to be at the same time adaptive to the local environment and resistant to diseases in order to also minimise the use of antibiotics.

1.3 MOTIVATION

South Africa is in a process of drawing up the national standards for the chicken industry that is aligned to international standards for organic agriculture (DAFF, 2015). The animal welfare issues of layers, related to limited space and restriction of natural behavioural expression due to use of conventional cages, is a challenge to the layer industry. The demand for organic or free-range poultry products has increased due to scientific evidence about human health risks that are associated with consumption of synthetic poultry products. This concern about the health risk of consumers and animal welfare had motivated researchers to find organic alternatives. The crossbreeding of indigenous chickens with hybrid vigour breeds can bring solutions of developing productive layer chickens that are not kept in conventional cages. The contribution knowledge of indigenous genotypes to egg production seems to be unknown in South Africa. Commercial Lohmann Brown layer will be used in the study as positive control to benchmark production of the crossbreeds and reciprocal crosses from 4 x 4 diallel crossbreeding. Therefore, this study conducted to determine which crossbreed chicken can perform better on egg production in South Africa when fed commercial layer diet.

1.4 AIM AND OBJECTIVES

1.4.1 Aim of the study

To determine if 4 x 4 full diallel crossbreeding has an effect on growth and egg production performance, egg parameters, genetics and phenotypic characteristics of crossbreed F1 offspring.

1.4.2 Objectives of the study

1. To determine the effects of crossbreeding on growth performance of F1 crossbreed compared to pure breeds on production traits and economic efficiency from day old to 18 weeks old chicks.
2. To determine which F1 offspring (crossbreed or reciprocal) from 4 x 4 diallel crossbreed produce more eggs than others with better economic efficiency.
3. To determine the effects of crossbreeding on the phenotypic characteristics on the body structures and feather pattern of the F1 offspring.
4. To determine if there is difference on general and specific combining ability and heterosis on phenotypic characteristics among F1 crossbreeds.
5. To assess the variation of egg parameters from production of different crossbreed F1 offspring.

1.5 HYPOTHESES

1. There are no effects of crossbreeding on growth performance of F1 crossbreed compared to pure breeds on production traits and economic efficiency from day old to of 18 weeks old chicks.
2. All F1 offspring (crossbreed or reciprocal) from 4 x 4 diallel crossbreed had equal egg production with same economic factor.
3. Crossbreeding of chickens does not have effects on the phenotypic characteristics of the chickens on the body structures and feather pattern.
4. There is no difference on general and specific combining ability and heterosis on phenotypic characteristics of F1 crossbreed.
5. There is no variation of egg parameters from production of different crossbreed F1 offspring.

1.6 SIGNIFICANCE OF STUDY

The study will contribute to academic knowledge. Develop an alternative layer breed that produce high number of egg production with low cost and adaptive features of future free-range system farming to produce organic egg products that are highly demanded in the market. The developed productive crossbreed can be used to fill the gap created by consumers' preference for organic eggs. The study will further benefit the researcher to complete a PhD degree in Agriculture with University of South Africa.

CHAPTER 2

2 LITERATURE REVIEW

2.1 INTRODUCTION

The poultry industry operates in competitive markets where poultry breeders are under pressure to produce chickens that meet the perceived needs of consumers. The production of food has changed, from being producer-driven to consumer driven (Besbes et al., 2007). The use of antibiotics in poultry feed, to improve performance and morbidity, started when Stokstad and Jukes added residues of chlortetracycline (Ferket, 2004; Falcão-e-Cunha et al., 2007; Buchanan et al., 2008) to the feed. There is growing scientific evidence internationally that shows that certain bacteria are becoming increasingly resistant to antibiotics. Antimicrobial resistance seem to be transferred from animals to humans through the consumption or handling of meat that contains resistant bacteria (Castanon, 2007; Oguttu, Veary & Picard, 2008). These concerns had led to the demand for organic food production, which would result in a product that is healthier, taste better and a system that takes into consideration animal welfare and is environmentally friendly (Hughner et al., 2007). However, Leenstra et al. (2014), emphasised that free range and organic egg production systems are quite complex due to many factors and their interactions that influence ultimate performance of flock when adhering to welfare. Policymakers at Netherland, decided to change production system based on sustainable assessment for animal welfare, environmental impacts, food safety and economic vitality of the producer (van Asselt et al., 2015).

Since the late 1950s, poultry breeding companies have worked hard with producers to revolutionise the production of poultry meat and eggs (Hughner et al., 2007). The customers' demand for organic poultry products will lead to complex of breed selection with the effects of nutritional and environmental requirements for organic farming**.** Both small-scale and commercial farming should be reliable, predictable and use suitable models to produce organic poultry products. The demand for organic poultry products around the world led to continuous genetic changes with the addition of a free-range genotype (Mons, 2012). The focus of breeding will be on both animal health and welfare, with careful consideration to environmental issues by the producer to meet the requirements of both retailers and consumers (Castellini et al., 2008; Mckay, 2009).

Researchers need to focus on the strength of genotypes or strains of chickens that are capable of adapting and be productive in a range of commercial environments (Besbes et al., 2007). The demand for organic or free-range poultry products will affect current investment protocols and require new investment in research, genetic development, production facilities and distribution systems. However, these changes will enable both the breeding and producer companies to maintain their competitive position in the international market of organic products (Mckay, 2009). Production prediction models will increase in sophistication and remain a valuable tool for research purposes and formulation of practical diet solutions for organic poultry products. The maintenance of the immune-competence and optimal health status of chickens in a range of husbandry situations will remain a priority. Nutrition plays a critical role in achieving this, since it gives opportunity for full expression of genetic potential to complement the process of genetic selection (Chadd, 2007). The performance capabilities and phenotypic expression of layers and broilers, in both commercial and backyard situations, are determined by the effects of a combination of genetic and environmental factors (Chadd, 2007; Razuki & Al-Shaheen, 2011).

2.2 CHICKEN BREEDS

The majority of commercial poultry strains appear to be derived from the White Leghorn, Rhode Island Red, Plymouth Rock, New Hampshire and White Cornish breeds (Besbes et al., 2007). The utilisation of poultry genetic resources is the best mean to ensure that they remain available for future offspring. To be sustainable, this resource must have the capacity to meet the current economic and social objectives without compromising the natural environment and resources (Besbes et al., 2007). The situation varies greatly between the commercial populations, kept in high-input production systems, and the indigenous populations, kept in subsistence-oriented and low-input systems. The breeds and strains used in intensive production are prone to disease and other health problems that are sequentially, passed on to humans through consumption. However, for organic production to be viable, preference should be given to indigenous breeds and strains of breeds that are adapted to local conditions (Duncan, 2009). The dual-purpose chicken breed was developed in South Africa at Research institute of Animal Husbandry and Dairying by crossing of Black Australorp cockerels with White Leghorn hens. The F1 hens were mated with Plymouth Rock for final registration of Potchefstroom Koekoek breed (Packard, 2014). Potchefstroom Koekoek breed produce 196 eggs per hen to outperform indigenous Naked neck hens that produce 139 eggs per hen at the age to 52 weeks (Grobbelaar, 2008). Lohmann Brown layers are well known worldwide for high egg production for more than 60 years (Habig, Geffers & Distl, 2012).

2.3 CHICKEN BREEDING

Chicken breeding objectives comprises of pure breeding and crossbreeding. According to Okeno, Kahi & Peters, (2013), the objectives of pure breeding of indigenous chickens are selected in the nucleus and offspring not selected to replace parents passed on to the multiplier to produce offspring for breeding in commercial sector. The breeding goal for chicken breeders is to ensure gradual adaptation to the trends identified in current and future market demands. The breeding goals that determine which egg-type strains will be selected are based on requirement for high egg output, efficient feed conversion ratio and egg quality as preferred by the egg processing industry, retailers and consumers (Flock, Laughlin & Bentley, 2005). Breeding for meat and egg production is a complex process involving effective and accurate selection. Selection for numerous traits in the sire and dam lines is important to ensure that the final crossbred chickens possess all the required attributes. Breeding programme are very costly (Anim, 2011). A large population with significant numbers of active and reserve sire and dam lines is required to permit the full exploitation of genetic variation in the component traits and to reduce the effects of inbreeding (FAO, 2009).

Globally, the goal for the breeding of chickens is also linked to ultimately achieving safe food production thus how genetic potential cannot be viewed in isolation (Chadd, 2007). Most companies that produce the commercial hybrids kept their breeding information a secret (Besbes et al., 2007). There is a succession of breeding programme on large-commercial chicken companies. The succession starting at breeding unit (nucleus) is responsible for the development of pure lines and grandparent flock. The parent stock is crossbred to produce the multiplier unit and sold to the commercial sector for breeding and production purpose.

Breeding for resistance to a specific disease caused by micro-organisms involves exposure of the chickens to disease-causing microbes in controlled conditions. This cannot be done on a pedigree farm. For this reason, a disease challenge is sometimes carried out at an isolated location, using the siblings or progeny of the chickens under selection. Selection is based on the relative susceptibility of the families (Besbes et al., 2007). Indigenous chickens are adaptive to harsh environment and resistance to many diseases. The private companies often introduce the three-way crossbreeding strategy to accomplish the indigenous genes on the genotype. Three-way crossbreeding includes two dam lines and one sire of indigenous chicken which are selected to produce a hybrid for egg or meat production depending on breeding objective (Okeno, Kahi & Peters, 2013). The identification of genetic markers for resistance to a particular disease will enable a more focused selection, which does not require the evaluation of breeding stock through welfare-unfriendly challenge experiments. Other three-way crossbred using three breeds obtained from hatchery of Poultry Research Institute at Rawalpindi, Pakistan yielded significant results on egg production (Khawaja et al., 2013).

2.3.1 Layer breeding programmes

Commercial poultry breeding programmes have imposed high selection pressure to achieve rapid genetic gain at the earliest ages for meat production (2.0 to 2.4kg at 38 days) and sexual maturity for maximum eggs (315 eggs) per hen per year (Panda et al., 2011). The production performance for indigenous, exotic and their crossbred chickens in Ethiopia, revealed different mean ages of sexual maturity for indigenous at seven months, crossbred at six months and exotic at five months (Habte, Ameha & Demeke, 2013). Pure-line pedigreed chickens in breeding farms are housed in single-chicken cages in order to measure individual egg production and quality traits. However, commercial chickens are housed in multiple-chicken cages or in large pens. These conditions may be stressful and can result in injuries due to aggression, flightiness and cannibalism leading to high mortality and depression of egg production. To select chickens that can cope with these conditions, layer breeders conducted several tests representative of field conditions in different geographical regions. The assumption behind these tests is that the effects of housing type on animal welfare cannot be isolated and should be studied independently from the effects of nutrition, management and local environmental conditions (Besbes et al., 2007).

2.4 CROSSBREEDING INDIGENOUS, EXOTIC AND COMMERCIAL CHICKENS FOR EGG PRODUCTION

There is evidence showing an existing considerable scope to improve the performance of local breeds by methods of crossbreeding (Besbes et al., 2007). The characteristics associated with indigenous breeds include late sexual maturity, poor egg production, slow growth, broodiness, smaller egg and body size. These characteristics are somehow disadvantaging the conservation of the indigenous breeds, and this has raised serious concern. Growth in poultry is influenced by the genotype of the chickens which is inherited from the dam or sire, and by nutrition, hormones, tissue specific regulatory factors and other aspects of the chicken's environment (Kingori et al., 2010). The goal of crossbreeding is to improve the efficiency of indigenous breeds under rural conditions. Indigenous chicken breeds serve as dual-purpose breeds, therefore, improving their performance through crossbreeding is expected to achieve high fertility rate, body weight, meat and egg production (Saadey et al., 2008; Besbes, 2009). Continuous evaluation, selection, monitoring and conservation of these flocks is important for proper management and use for development of productive genotypes (Mtileni et al., 2016).

The exploitation of genetically diverse indigenous chickens for improving economic traits, such as body weight is one of the approaches driving the breeding programme of chickens (Saadey et al., 2008). The crossbreeding in poultry is performed by artificial insemination and natural mating using standard ratio of cocks to hens. There is a wide variation in both the mating frequency and the mating efficiency of cocks and little relationship between the traits and fertility (Hocking, 2009). These discoveries mean that the mating dynamics in large commercial flocks of breeders is extremely complicated. The ratio of 1 cock to 10 hens give the best fertility results. The decline in fertility in broiler cocks after 50 weeks of age has been noticed with a suggestion that this is probably due to the conformation of the cocks preventing cloacal contact rather than a reduction in libido (Hocking, 2010).

Crossbreeding of indigenous and exotic is identified as effective method to improve the productive ability of indigenous breeds regarding eggs and meat (Okeno, Kahi & Peters, 2013; Padhi, Chatterjee & Rajkumar, 2014; Musa et al., 2015). The researchers and some breeders have taken recourse to the introduction of high yielding exotic germplasm to the indigenous breeds (FAO, 2011). The breeding systems adopted include crossing of exotic breeds with local breeds to improve productivity. The back crossbreeding of F2 generation with exotic chickens yielded negative correlation on egg production on the study conducted in Uganda, aiming to improve performance of local chicken breeds (FAO, 2009). The genetic impacts of these formal and informal cross-breeding schemes and practices are unknown. As a consequence, identification of pure indigenous chickens may not be original due to lots of crossbreeding that occurred in most developing countries (Mtileni et al., 2016). The merger and acquisition of breeding companies in poultry industry, led to the loss of large genetic resources in chicken breeds (Besbes et al., 2007).

The crossbreeding study conducted during 1950s with a selection in a non-descript flock of Indian Deshi fowl revealed improvement in egg production (Besbes et al., 2007). This crossbreeding led to increased production of eggs from 116 to 140 eggs, with an average egg weighing 43 to 49 g per hen through six offspring of selection.

2.5 NUTRITIONAL REQUIREMENTS FOR EGG LAYING CHICKENS

Feed and water are essential for living animals. To meet the nutritional requirements of any breed of chicken, there is a need to be accurate of ration formulation for that breed of chicken. Different breeds of poultry have different nutrient requirements. In commercial production, for an example, diet specifications for broilers versus layers are deliberately differentiated (Chadd, 2007). The exploitation of chicken genes in a free stress environment, by giving chickens an adequate balance diet with essential nutrients resulted in improved growth performance to the highest genetically limit (Kingori et al., 2010).

Ration formulation is the process of quantifying the amount of ingredients that need to be combined to meet nutrient requirements of chickens. Therefore, the process of ration formulation requires an intimate knowledge of the chicken, its daily nutrient requirements, its physiological needs and a more comprehensive understanding of the ability of the selected feeds to provide the most desirable nutrients. The ingestion of the optimal level of dietary nutrients for parent stock, broilers, layers, indigenous or any other type of chickens is highly dependent on the level of feed intake (Chadd, 2007). The feed efficiency in layers is defined in terms of the kilograms of feed required to produce one kilogram of eggs. Genetic improvements in productivity continue to improve the use of resources such as feed and energy. The improved genetics lead to the need for enhanced digestible efficiency of amino acids and phosphorus (Besbes et al., 2007). The reproductive performance attributed to a modified body composition at the onset of lay can be highly associated to feed management during rearing (Van Emous et al., 2015).

2.5.1 Protein requirements

The specified protein requirements for a particular chicken genotype is very important to enhance its potential maximum performance. According to Van Emous et al. (2015), the differences in body composition at the end of rearing is often influenced by the level of protein intake. The effects of protein excesses on growth performance are due to the changes in the voluntary feed intake (Thu et al., 2009). Feeding animals below their protein requirement does not improve protein utilisation. Protein deficiency in feed reduces growth as a consequence of depressed appetite and, intake of nutrients (Kingori et al., 2003). Smith & Pesti, (1998) reported that the body weight increased at a decreased growth rate with an increase in protein level, and with a slight increase in the feed intake of the cross-broiler strain. Van Emous et al., (2015), proved that differences in body composition of pullets resulted from different levels of protein intake during rearing can disappear during laying period. However, Dairo et al., (2010) reported that an increase of dietary protein levels will reduce the total feed intake and improve final feed conversion ratio (FCR).

Economic evaluation on the decreasing CP levels from 23% to 20% resulted in reduced feed cost per kilogram of live body weight gain. The feeding of diets of varying dietary protein levels (17.72 – 21.52%) did not differ significantly on the effects of final live weight, feed intake, body weight gain, FCR and water intake of the broiler chickens (Folorunso & Onibi, 2012). Kamran et al., (2008), discovered that reducing dietary CP did not affect the growth performance of the chicken and it can be used to reduce feed cost with supplementation of relevant alternate feedstuffs are supplemented. However, different results were observed on layers, where the egg weight of hens fed high-protein diet was significantly greater than that of hens fed the low-protein diet during 97 and 98 weeks of age (Gunawardana, Roland & Bryant, 2009). Feeding the hens high level of protein did not result in an increased protein deposition, however, nitrogen excretion through the urine increased rapidly (Kingori et al., 2010).

The CP requirement for broilers differ during the different growth phases. The pre-starter fed from 0 to 10 days of age contains CP of 22.5%, starter fed from 11 to 21 days of age contains CP of 21.0% and grower fed from 22 to 42 days CP of 19.5% (Panda et al., 2014). The protein requirements for layers is lower than that of broilers.

(Shim et al., 2013), formulated four diet treatments with three levels of protein and the outcome revealed that the increase in protein level, increased cost and returns.

2.5.2 Energy requirements

Energy is one of the most important components of food and therefore it generates a lot of interest and challenges to all animal nutritionists. Researchers in the field of nutrition are very determinants in the evaluation of the performance and production coefficients on farm animals (Dairo et al., 2010). Energy is produced when the feed is digested in the gut. Energy may be released as heat or it is trapped chemically and absorbed into the body for metabolic purpose. The wide range of dietary energy levels (2,684 to 2,992 kcal of ME/kg) was recorded (Yuan et al., 2009).

Dietary energy is continuously investigated in the poultry industry across the world because the increase of dietary energy has effects on general performance of the chickens. Wu et al. (2005) reported that when the diet with increased dietary energy levels resulted in linearly increased feed intake from 107.6 gram (g) to 101,1 g per hen per day. This resulted in a net increase of 6.5 g per hen per day or 6% of the overall feed intake. The egg production, egg weight and egg mass (in gram of egg per hen per day) was not affected by increased energy on diet by 7.5% (2,795 kcal ME/kg diet) compared to a control group at (2.600 kcal ME/kg diet) (Panda et al., 2012). Feed intake and egg weight can affect cost of production and profits. The energy and lysine ratio required for optimal profits varied with egg price and feed ingredient price, which were variable (Wu et al., 2005).

2.5.3 Lysine requirements

Lysine is regarded as the key amino acid for poultry whereby the concentrations of the other amino acids may be related to it. The maintenance requirements for the number of amino acids, including lysine and threonine, per adult rooster were determined by using a mathematical model (Leveille, Shapiro & Fisher, 1960). Lysine is one of the first and limiting amino acids found in corn-soybean meal diet for laying hens (Alagawany & Mahrose, 2014). The maintenance of amino acid requirements are often defined at nitrogen (N) equilibrium, the state in which N intake equals the sum of N losses where the N content of the body remains constant (Nonis & Gous, 2008). However, there is considerable research that directs towards defining the minimum intake of dietary CP and amino acids to reduce the nitrogen in the excreta in order to reduce nitrogen loss to the environment (Waguespack et al., 2009). The pullet body requirements changed rapidly during the growth stage and the amino acids had to be adjusted accordingly. After certain growth stage the body of pullet remain constant and requirement of amino acids can be perfectly matched (Sakomura et al., 2015). The limitation of non-essential amino acids, can result in limited protein synthesis and reduce egg production (Cristina et al., 2013).

Nonis & Gous (2008) reported that most authors approached the problem of estimating the amounts of amino acids required for maintenance using response trials with populations of laying hens or growing chickens. The developed ready model has been used to estimate the coefficients of response (amino acids (mg) required per egg output (g) per body weight (kg) daily) to amino acids intake in laying hens (Fisher, Morris & Jennings, 1973). The factorial approach should be used to determine the amino acids requirements for boilers and layers, and to estimate the requirements of growth or egg production and another body maintenance (Nonis & Gous, 2008; Bonato et al., 2016). The accurate estimation of amino acids is essential if nutritional decisions are to be based on calculations. The calculations in simulation model can be used to predict average food intake per chicken and expected performance (Nonis & Gous, 2008; Bonato et al., 2011). The least square of means value, of 4.80 g lysine/kg diet, determined the slope of the line below the estimated lysine requirement for broiler breeders. The mean requirement of 4.88 ± 0.96 g lysine/ kg diet or 365.6 ± 62.6 mg lysine per broiler breeder hen day was obtained (Coleman et al., 2003).

2.6 PERFORMANCE OF INDIGENOUS, EXOTIC AND COMMERCIAL CHICKENS DURING REARING

There was no variation in feed intake and weight gain between two Pakistan local breeds, Desi and Fayoumi under a control environmental management housing system with stocking density of 15 chickens per m^2 (Khawaja et al., 2013). However, the exotic Rhode Island Red breed consumed more feed and gained more weight than two local breeds at all ages of growing phase. At 20 weeks of age, body weight was as follows, Desi 1 180 g, Fayoumi 1 166 g and Rhode Island Red 1 640 g (Khawaja et al., 2012). The two indigenous chickens were out-performed by the broiler strain on the growth trial as from the age of 8 weeks. However, growth performance of the indigenous Naked neck was better than exotic egg-type breeds. In comparison of growth rate for three breeds in South Africa, Potchefstroom Koekoek was reported to have the lowest growth rate and efficiency of feed conversion ratio compared to Black Australorp and Ovambo chicken breeds (Sebola et al., 2015). The Lesotho local chicken yielded competitive growth performance when compared to Rhodes Island Red. The Lesotho cocks weighed 2 350 g while, Rhodes Island Red cocks weighed 2 962 g. The Lesotho hens achieved 2 047 g higher than Rhodes Island red with 1 778 g all at age of 70 weeks. These two breeds were out-performed by New Hemisphere with body weight, average daily gain and FCR at age of 70 weeks (Nthimo et al., 2006).

2.7 COMPARISON OF EGG PRODUCTION BETWEEN PUREBREED, CROSSBREED CHICKENS AND THEIR CROSSBREED OFFSPRING

Razuki & Al-Shaheen, (2011), compared egg production between White Leghorn (WL), Brown Line and New Hemisphere (NH) and their crossbreeds under a divided pen house with controlled light and heat. The study revealed that White Leghorn produced an average of 62 eggs per hen while Brown line and New Hemisphere produced 61 eggs for 100 days. However, the following crossbreeds laid more eggs than the pure breeds at same the age, WL x NH 67 eggs, Brown line x New Hemisphere 64 eggs and White Leghorn x Brown line laid 63 eggs (Razuki & Al-Shaheen, 2011). These performances of egg production measured on crossbreeds at the age of 52 weeks. The

F2 generation out performed F1 crossbreeds whereby Native Udaipur x Rhode Island Red x Rhode Island Red (NU x R x R) produced 121 eggs (Padhi, 2016). The second position held by Rhode Island Red x Native Udaipur with 119 eggs. In the third position for meat-type synthetic breed x Native Udaipur x Rhode Island Red (PB2 x NU x R) with 110 eggs. In general, Rhode Island Red improved the productivity of indigenous breeds through crossbreeding at F1 and F2 generation where three-way crossbreeding was practiced.

2.8 ECONOMIC EFFICIENCY FACTOR IN AGRICULTURAL BUSINESS

The economic efficiency refers to the value of all inputs used to obtain a product, effective production or productivity, profit or profitability and savings. Business production is economically efficient when the gross return can be subtracted from total overheads, variables and production inputs related to specified product. The economic efficiency for animals include the entire operational cost aligned to animals in the farm, number and value of animal products selected for future production and return on sales (Anim, 2011). According to Chetroiu & Calin, (2013) the economic efficiency is a complex economy category, in which operation of economic laws is reflected and the most important economic activities are manifested. Giannakis & Bruggeman (2015), discovered that high economic performance of agriculture in European countries increased with increased levels of gross fixed capital formation. The increase was associated with trained youth on agriculture who were capable on innovative strategies and use of advance technology. The economic performance on farms was assessed using gross value-added indicators that have been used often for measuring industry`s economic performance.

2.9 GENERAL COMBINE ABILITY, SPECIFIC COMBINE ABILITY, HETEROSIS AND MATERNAL OF PURE AND CROSSBRED GENOTYPE

Combining ability analysis helps in the identification of parents with higher general combine ability (GCA) and parental combination with higher specific combining ability (SCA). According to Zhao et al., (2014), higher SCA indicates non-additive gene effects and higher GCA effects refer to a greater role of additive gene effects controlling these characters. Furthermore, the parent B5, B8 and MB15 had higher GCA values in tree height (H), diameter at breast height (DBH) and stem straight degree (SSD) respectively and they were considered as excellent parents to improve the homologous traits. The commercial breed Ross 308 had positive GCA on body weight compared to two indigenous chickens (Venda and Naked neck breeds) (Siwendu et al., 2013). However, SCA estimates were all negative for all weight measurements between Ross 308 x Naked neck, while there was a positive yielding between two indigenous Venda x Naked neck for all body weight measurements. The Ross 308 had positive effects on Venda where all SCA estimates were positive for all the body weight measurements except in third and fifth week.

2.10 EFFECT OF CROSSBREEDING ON EGG PARAMETERS

The effects of crossbreeding two indigenous breeds (Fayoumi and Desi) with exotic chickens (Rhodes Island Red) were noticed on the body improvement, egg production and egg parameters (Khawaja et al., 2012). Rhodes Island Red showed significant difference to Fayoumi and Desi breeds on the internal egg quality parameters, which included yolk weight, albumen weight, yolk-albumin weight and albumin height. In addition, egg production had a strong relationship with physical egg characteristics and yielded significant differences in various egg characteristics among three breeds. The crossbreeding between Aseel x Dahlem Red increased annual eggs from 91 to 189 eggs on crossbreed offspring (Padhi, 2016). Furthermore, it was revealed that crossbreeding between Dahlem Red and Palampur native breeds had positive effects on improvement of egg parameters by increasing egg weight from 42.48 g to 52.43 g. All major economic traits like eggs were improved in the crossbreeds compared to native chickens proving to be one of the tools that can be used to improve performance of indigenous chickens.

CHAPTER 3

3 METHODOLOGY

3.1 STUDY SITE

This study was conducted at the Agricultural Research Council (ARC), Livestock Production Institute at the Irene Campus with GPS coordinates 28 12' 51.6" E. The area has a typical Highveld climate (altitude 1 523 m) with hot days and cool nights in the summer and moderate temperatures during the days with cold nights in the winter.

3.2 EXPERIMENTAL DESIGN

The study was divided into two phases. Phases 1 started with the hatching of fertile eggs of four pure breeds, continue to rear, crossbreeding experiment end with production. Phase 2 started with the hatching of pure breed and crossbreed chicks, continue to rear of breeds, production process and egg parameters. During peak production and the last phase of production on both phase 1 of parent and phase 2 of F1 offspring, samples of eggs were incubated to determine the fertility, embryonic mortality, shell quality and hatchability percentage among all groups. All data were organised accordingly in the excel spreadsheet and set for statistical analysis.

3.2.1 Experimental design for phase 1 with 4 x 4 full diallel crossbreeding of four breeds

A full diallel design of 4 x 4 pure strains were chosen, to estimate the total heterosis. The 4 x 4 full diallel allow the analysis of total heterosis components and comparison of genotype performance according to the strains and hybrids (Brenøe, 1996). The 4 x 4 full diallel crossbreeding between exotic and local breeds was done with the aim of combining better production capacity and adaptability to harsh environments in the next offspring (Besbes 2009). Table 3.1 represents the layout of the 4 x 4 full diallel cross.

The total number of 352 chickens (16 cross) were used in phase 1 of the study which is crossbreeding of pure breeds. Each crossbreeding treatments had the total number of two cocks and 20 hens per crossbred in phase 1 of the experiment. Each cross group had two replicates whereby each replicate consisted 1♂ & 10♀. The layout of the phase 1 experiment is presented in Table 3.2 in first left column and third column with sixteen cross groups.

Table 3.1: Full 4 x 4 diallel - each parent mated with every other parent in the population, to produce pure breed, crossbreed and reciprocal.

	♀				
		nn	**pk**	**Wl**	**lb**
	NN	NNnn	NNpk	NNwl	NNlb
♂	**PK**	PKnn	PKpk	PKwl	PKlb
	WL	WLnn	WLpk	WLwl	WLlb
	LB	LBnn	LBpk	LBwl	LBlb

NN-male, **nn-**female= Naked neck, **PK**-male, **pk**-female = Potchefstroom Koekoek, **LB**-male, **lb**-female = Lohmann Brown and **WL**-male, **wl**-female = White Leghorn

3.2.1.1 Experimental procedure for phase 1

The fertile eggs of the four breeds (White Leghorn, Potchefstroom Koekoek, Naked neck) were bought from ARC poultry unit and accredited poultry breeders. Day old Lohmann Brown chicks were purchased from accredited commercial hatchery called Bergvlei and brought on the same day of hatching for simultaneous placement. The eggs were incubated on the same day to allow one hatching time and in order to obtain a uniform age during the entire study. The chicks were placed in the same house in different pens per breed. The body weight of day-old chick for all breeds were measured during placement and weekly for growth performance. All breeds were fed the same commercial rearing and grower mash. Data capturing form was used to record all the required information daily and every activity per pen including weekly growth measures. At the age of 12 weeks old the breeds were mixed according to experimental design before sexual maturity is reached, to allow enough time for adaptability among the breeds. At the age of 18 weeks old final selection was done among the breeds, to select the best hens and cocks for experiment. The selected chickens of different breeds were grouped in different pens according to the experimental design.

At the age of day-old, the starter mash was fed, grower mash was fed at 7 weeks of age during rearing phase and layer diet was fed when chickens reach 19 weeks of age. The layers were fed peak phase and post peak phase diet according to the manufacturer's recommendation. The daily records per pen including the number of eggs, feed added (kg) and mortality were done. The example of the form is presented in Appendix A. Monthly records per pen included feed consumption, body weight and hen-housed eggs.

3.2.1.2 Experimental design for phase 2

Phase 2 of experiment consists of sixteen treatments of F1 offspring from sixteen breeding groups in phase 1 of the research project. Table 3.2 below shows the random placement of pure breed and crossbreed chickens in phase 2. The total number of 384 chickens (16 F1 x (3 cocks + 21 hens)) were used in phase 2 of experiment and placed randomly in 16 pens. Initially, the plan experimental design was to place treatments with the replicates at ration of 1 male: 7 hens per pen to a total 48 pens. The purpose of random placement for each treatment per pen was to allow computing the variability of measurements within each unique combination of feed and cock factor levels on ratio of seven hens. This variability should give an indication of the random error in the measurements. Such an estimate of the pure error can be used to evaluate the size and statistical significance at the P value of (0.05) of the variability that can be attributed to the manipulated factors (IBM Corporation, 2017).

Table 3.2 Random placement of pure breeds and crossbreeds chickens on pens during phase 2 of research study

Random placement in research house	
LBnn (3 ♂:21 ♀)	NNnn (3 ♂:21 ♀)
PKwl (3 ♂:21 ♀)	WLpk (3 ♂:21 ♀)
WLwl (3 ♂:21 ♀)	PKpk (3 ♂:21 ♀)
LBlb (3 ♂:21 ♀)	NNlb (3 ♂:21 ♀)
WLnn (3 ♂:21 ♀)	PKlb (3 ♂:21 ♀)
NNpk (3 ♂:21 ♀)	LBwl (3 ♂:21 ♀)
WLlb (3 ♂:21 ♀)	NNwl (3 ♂:21 ♀)
PKnn (3 ♂:21 ♀)	LBpk (3 ♂:21 ♀)

NN-male, **nn-**female= Naked neck, **PK**-male, **pk**-female = Potchefstroom Koekoek, **LB**-male, **lb**-female = Lohmann Brown and **WL**-male, **wl**-female = White Leghorn

3.3 FEEDING OF CHICKENS DURING EXPERIMENTAL RESEARCH

Different feeding phases were applied according to the age stages of the chickens as recommended by the manufacturer. The pullet starter mash was used as the first phase feed to rear chickens from day old to six weeks of age. Table 3.3 present the composition of nutrients used to feed chickens from pullet starter to post peak production diet. The manufacture recommended the approximate consumption 1.1 kg per chick for six weeks (Meadow Feeds, 2017).

The pullet grower mash was used as the second phase feed to rear chickens from 7 weeks to 12 weeks of age. The manufacturer recommended the approximate consumption of 2.3 kg per chicken for six weeks (from 7 to 12 weeks of age).

Table 3.3: Composition of nutrients of used diet from pullet starter to post peak production.

Nutrient	Starter	Pullet Grower	Pullet Developer	Early Lay	Peak lay	Post Peak	Unit g per kg
Feeding Regime	0 to 6 weeks	7 to 12 weeks	13 to 18 weeks	19 to 35 weeks	36 to 50 weeks	51 to cull	
Protein	190	160	120	150	130	130	g/kg
Fat	25	25	25	25	25	25	g/kg
Fibre	70	80	100	70	70	70	g/kg
Moisture	120	120	120	120	120	120	g/kg
Calcium (Min)	8	8	8	35	27	35	g/kg
Calcium (Max)	12	12	15	45	45	45	g/kg
Phosphorus	6	6	6	5	5	5	g/kg
Total lysine	7	6	4.5	6	5	5	g/kg

The pullet developer mash was used as the third phase feed to rear chickens from 13 to 18 weeks of age. The manufacturer recommend the approximate consumption of 3.7 kg per chicken. The early layer mash used as the fourth phase feed during early stage of egg production period and fed to chickens from 19 to 36 weeks of age. The manufacturer estimated the consumption to range between 9 and 11 kg per chicken for period of 18 weeks.

The peak layer mash was used as the fifth phase feed during egg production period, fed to chickens from 36 to 50 weeks of age. The manufacture estimated the consumption to range between 10 and 11 kg per chicken for period of 15 weeks. The post-peak layer mash was use as the sixth phase feed during egg production period of chickens, fed from 51 weeks to culling period. The manufacturer estimated the consumption to range between 13 and 14 kg per chicken for period of 25 weeks or more.

3.4 THE PROCESS OF RESEARCH EXPERIMENT IN TWO PHASES

3.4.1 The process of phase 1 experiment

The fertile eggs for three breeds (Potchefstroom Koekoek, Naked neck, and White Leghorn) were bought from the Agricultural Research Council (ARC). Day old Lohmann Brown chicks were purchased from accredited commercial hatchery called Bergvlei. Chicks were brought to the ARC, Irene campus, on the hatching day of other three breeds. The synchronization of hatch and delivery on same day was to ensure that all the chick of four breeds are placed at the same time to get a uniform age and to be able to rear the chickens under the same conditions. The mating design was a full diallel crossing of four breeds (4 x 4 full diallel) to allow all possible combinations (sixteen crosses), thus, these genotypes will produce four pure breeds, six crossbreeds and six reciprocal crosses (Razuki & Al-Shaheen, 2011).

Chickens from all treatments were fed commercial feed composition that is presented on Table 3.3 above. The growth traits and feed intake of four pure breeds, six crossbreeds and six reciprocals were measured weekly from day old to laying of eggs. The body weight, feed intake, feed conversion ratio and economic efficiency were determined and analysed every second week starting at the rearing stage and ending at the end of the lay period. The age at sexual maturity, egg production, egg weight, and percentage of egg fertility were recorded and analysed during the laying period of crossbreeding and pure breeding. During the laying period, egg production was recorded daily to compare egg clutch among pure breeds and crossbreeds. The White Leghorn and Lohmann Brown layer were crossbred with Potchefstroom Koekoek breed and Naked neck to determine if they can enhance the genes to improve egg production on their offspring.

3.4.2 The process of phase 2 experiment

3.4.2.1 Rearing period for F1 offspring

The hatched day-old chicks comprising of 16 treatments from (4 x 4 full diallel cross) in phase 1 of the study were used in phase 2. The normal production parameters were measured during the rearing stage. The chicks were raised under the same house with commercial rearing mash and grower mash during the rearing stages. At the age of 18 weeks, the required number of chickens were selected and grouped according to the experimental design for crossbreeding to allow the adaptability process. Twenty four chickens from each breed of sixteen treatments were randomly placed at the ratio of one cock to seven hens (1:7). The two rations, starter feed chicks up to age of 6 weeks and grower mash from seven to eighteen weeks of age were fed to all treatments with same composition of nutrients as presented in Table 3.3, before their sexual maturity. The chickens were placed on the floor pen during rearing and egg laying period.

3.4.2.2 Collection of data for phenotypic characteristics

During phase 1 of rearing, at the age of 18 weeks, 80 chickens were randomly selected (10 cocks and 10 hens) from four pure breeds and were subjected to phenotypic characteristics measurement. The phenotypic characteristics data were recorded and analysed. Similar phenotypic characteristics data were collected in phase 2 experiment at age of 18 weeks from 80 chickens (5 cock and 5 hens from sixteen treatments) to determine the heritability of phenotypic characteristics on the F1 offspring that were reared for phase 2. The example of phenotypic characteristic data collection form is presented at appendix B. The parameters of data collected on the form include the head parts, body length, body weight, chest circumference, shank colour and length, feather colours and length. The methodology was design and modified from phenotypic characterization of animal genetic resources (FAO, 2012).

Electronic scale measuring in grams was used to measure the body weight of each chicken. Textile measuring tape (1500 mm) was used to measure the lengths gathered for phenotypic characteristics. Vanier calliper was used to measure shank thickness. All phenotypic colours were standardised on the data collection form and code with numbers. The adjustment of feather colours was made for the colours that were not appearing on the form especially the combination colours.

3.4.2.3 Collection of data during laying period

The nest boxes were placed in each pen and the chickens were trained to use the nest boxes during the first two weeks of production. The feeds were weighed and recorded per pen every time the chickens were fed. The eggs collected and recorded in the mornings on daily basis, with the cut off time for egg collection was 10:00 am for all pens for accurate daily production record. Production parameters like feed intake, weight gain, feed conversion ratio, production percentage and economic efficiency factor were recorded for further statistical analysis.

3.4.2.4 Collection of data for egg quality analysis

Sample of ungraded eggs from all breeds were taken to the laboratory for egg quality analysis. The measurement for egg quality analysis included: egg weight, egg circumference, egg shell colour, egg shell thickness, albumen spread, albumen height, yolk colour, yolk height, yolk spread, yolk weight, and blood spot availability. Textile measuring tape was used to measure the egg circumference on the length and the width in mm. The digital verneir calliper was used to measure the egg height and width in mm.

Eggs were weighed individually by small electronic scale that is calibrated to measure weight in grams with two decimal numbers. The eggs were broken on mirrored table to measure albumen spread, height, yolk colour, yolk spread, yolk height. Eggshells were measured in same scale. The yolk separator was tare on the scale then used to separate yolk from the albumen to measure the yolk weight on the scale.

The three-leg tripod micrometer (Mitutoyo gauge) was calibrated to measure height in mm was used to measure yolk height and albumen height. Digital vernier calliper was used to measure the egg circumference (height and width) and egg shell thickness. The Roche Yolk Colour Fan was used to determine the colour of the yolk visually to the CIE standard colorimetric system. Roche Yolk Colour Fan is the standardized tool that shows the range of colours from one (very light yellow colour) to fifteen (very dark yellow colour).

3.5 DATA ANALYSIS FOR RESEARCH STUDY

Generic parameter calculations for diallel crossbreeding was done in both phases and at different stages to enable easy statistical analysis of the data that will be collected. The generic parameters included growth rate, feed intake, feed conversion ratio, fertility, hatchability of eggs set per sire/dam, egg quality, production percentage and economic efficiency. Full factorial analysis of variance (ANOVA) design was considered to analyse variables representing combinations of two or predictors that are more categorical. For example, study of interactions between breed-type and feed consumption and egg production. The statistical analyses were done using SPSS, General Linear Model procedures and probability was determine at $P < 0.05$ (IBM Corporation, 2017).

Scheffe and Least Significant Difference (LSD) were two post hoc tests used in the study to perform multiple comparison of the means from different variables per sex per breed and combine sex per breed. Scheffe is the most popular post hoc procedure that is flexible and conservative. Scheffe`s procedure can correct the alpha for all pair-wise and perform simple and complex comparisons of means.

3.5.1 Phase 1 data analysis

3.5.1.1 Phase 1: rearing period of pure breeds

The general linear model (GLM) procedures using IBM SPSS version 24 were used to assess the growth rate of the pure breeds, and the effects of feed consumption on body weight during the rearing period (IBM Corporation, 2017). The General Linear Model was used as follow:

$$Y_{ijk} = \mu + B_i + S_j + F_k + (BS)_{ij} + (BF)_{ik} + e_{ijk}$$

Y_{ijk} = Growth rate of chicken (weight grams) or percentage of the component Y of the $_{ijkl}$ breed

μ = Grand mean**;**

B_i = fixed effect on the breed group (i= 1....16);

S_j = fixed effect on the sex (j= 1, 2);

F_k = fixed effect on the feed consumption (k= 1);

$(BS)_{ij}$ = the interactions between breed-type and sex;

$(BF)_{ik}$ = the interactions between breed-type and feed consumption;

e_{ijkl} = Random residual error normally distributed with zero mean variance;

Duncan`s multiple range test was used to test for significant differences between pairs of means.

3.5.1.2 Phase 1: Egg production of pure breeds and crossed pure breeds

General Linear Model procedures using IBM SPSS version 24 was use in this phase to assess pure line breeding and crossbreeding, sex, weight, feed consumption and body weight composition on egg production (IBM Corporation, 2017). Multiple comparison of egg production means among breeds was performed by post hoc test using Scheffe analysis. The following linear model used to analyse the data:

$$Y_{ijklm} = \mu + B_i + S_j + F_k + W_l + P_m + (BS)_{ij} + (BF)_{ik} + (SF)_{jk} + (BP)_{im} + (SW)_{jl}) + e_{ijklm}$$

Y_{ijklm} = Egg production percentage or the component Y of the Σ_{ijklm} breeding type

μ = Grand mean**;**

B_i = fixed effect on the breeding group (i= 1, 2, ...16)

S_j = fixed effect on the sex (j= 1,2)

F_k = fixed effect on the feed consumption (k= 1)

W_l = fixed effect on the weight (l = 1)

P_m = fixed effect on egg production (m= 1)

$(BS)_{ij}$ = the interactions between breeding-type sex

$(BF)_{ik}$ = the interactions between breeding-type and feed consumption

$(BP)_{im}$ = the interaction between breeding-type and production

$(SW)_{jl}$ = the interactions between sex and weight

e_{ijklm} = Random residual error normally distributed with zero mean variance

Scheffe post hoc test was used to analyse significant differences between pairs of means of different breed treatments.

3.5.2 Phase 2 data analysis

3.5.2.1 Phase 2: Growth performance during rearing period of F1 offspring

General Linear Model procedures using IBM SPSS version 24 was used to assess the F1 crossbreed-type, and feed consumption on body weight composition during the rearing period (IBM Corporation, 2017). The LSD post hoc test was perform to determine significant differences between the pure breeds and the F1 crossbreed with single sex and with the combination of sex per breed.

Significant differences between mean pairs of different breed treatments were compared by using the Scheffe post hoc test. The General Linear Model was as follows:

$$Y_{ij} = \mu + B_i + F_j + (BF)_{ij} + e_{ij}$$

Y_{ij} = Feed consumption during rearing per breed Y of the $_{ij}$ breed

μ = Grand mean**;**

B_i = fixed effect on the breed group (i= 1....16);

F_k = fixed effect on the feed consumption (k= 1);

$(BF)_{ik}$ = the interactions between breed-type and feed consumption;

e_{ijkl} = Random residual error normally distributed with zero mean variance;

Scheffe post hoc test was used to test for significant differences between pairs of different breeds means.

3.5.2.2 Phase 2: Phenotypic body structures at 18 weeks old during rearing period of F1 offspring

General Linear Model procedures using IBM SPSS version 24 was used to assess the F1 crossbreed-type, phenotypic body structures (body weight, body length, wingspan, chest circumference, shank length) at 18 weeks of age during the rearing period (IBM Corporation, 2017). Significant differences between mean pairs of different breed treatments were compared by using the Scheffe test. The General Linear Model was as follows:

$$Y_{ijklmno} = \mu + B_i + S_j + W_k + Ws_l + L_m + C_n + H_o\ (BS)_{ij} + (BW)_{ik} + (SW)_{jk} + (BWs)_{il} + (SWs)_{jl} + (BL)_{im} + (SL)_{jm} + (BC)_{in} + (SC)_{jn} + (BH)_{jo}) + (SH)_{jo} + e_{ijklmno}$$

$Y_{ijklmno}$ = Phenotypic body structure measures during rearing of the component Y of the $_{ijklmno}$ breed

μ = Grand mean**;**

B_i = fixed effect on the breed group (i= 1....16);

S_j = fixed effect on the sex (j= 1, 2);

W_k = fixed effect on the body weight n (k= 1);

Ws_l = fixed effect on wingspan n (l = 1)

L_m = fixed effect on body length n (m = 1)

C_n = fixed effect on chest circumference (n =1)

H_o = fixed effect on the leg shank height. (o = 1)

$(BS)_{ij}$ = the interactions between breed-type and sex;

$(BW)_{ik}$ = the interactions between breed-type and body weight;

$(SW)_{jk}$ = the interactions between sex and body weight

$(BWs)_{il}$ = the interactions between breed and wingspan

$(SWs)_{jl}$ = the interactions between sex and wingspan

$(BL)_{im}$ = the interactions between breed and body length

$(SL)_{jm}$ = the interactions between sex and body length

$(BC)_{in}$ = the interactions between breed and chest circumference

$(SC)_{jn}$ = the interactions between sex and chest circumference

$(BH)_{jl}$ = the interactions between breed and leg shank height

$(SH)_{jl}$ = the interactions between sex and leg shank height;

e_{ijkl} = Random residual error normally distributed with zero mean variance;

Scheffe was used to test for significant differences between pairs of different breeds means.

The effects between the phenotypic body structure variables tested by corrected model, intercept and breeds deviation on sum squares and the mean squares. The partial estimate for sum square and mean square of each phenotypic body structure variables was calculated and the confidence interval of 95%. The analysis of phenotypic body structures was performed to establish other variable traits that can be considered when selecting the pullet at a point of lay for high productivity and economic efficiency. Comb and wattle sizes were measured to analyse the level of suppression and inheritance on genotype when compared to their parent sire and dam used on crossbreeding. The measured phenotypic characteristics of head variables were treated per sex on genotype to distinguish the differences.

3.5.2.3 Phase 2: Egg production of F1 offspring

The egg production data for phase 2 were analysed for variation between the pure breeds, crosses and within crosses of progeny using the general linear model procedure under SPSS (IBM Corporation, 2017). Significant differences between means of different treatment was performed by multiple comparison using the Scheffe post hoc test. The following general linear model was used to analyse the data:

$$Y_{ij} = \mu + T_i + e_{ij}$$

Where:
Y_{ij} = The i^{th} observation on the cross of j^{th}
μ = The overall mean
T_i = The fixed effect of i^{th} genotype (line or breed) group
e_{ij} = Random error assumed to be independently randomly distributed

General Combining Ability (GCA) is define as the average performance of breed, strain or line in a cross combination. The GCA for F1 offspring resulted from crossbreeding was analysed to determine the variance between pure genotype means and the developed crossbreed. The trait estimation for sixteen 4 x 4 diallel crosses was as follow: [$GCA_j = (\Sigma y_i/n) - \mu$], where GCAi = the GCA for line $_i$ (White Leghorn (WL), Potchefstroom Koekoek (PK), Naked neck (NN) and Lohmann Brown (LB) genotype). Y_i = Trait for F1 offspring with either one his pure parent breed line. I and μ presents the overall mean for given trait estimated from all sixteen diallel crosses (Aggarwal et al., 1979; Razuki & Al-Shaheen, 2011).

The specific combining ability was calculated as follow: SCA_{ij} = cross effect (GCA_i + GCA_j), where the cross effect = certain trait mean of given cross-overall mean of certain trait, GCA_j = the GCA for the line j (used pure genotype in study W, PK, NN and LB). The SCA formula used according Saadey et al., (2008) and it was as follow for LB and PK offspring: SCA = {(LBPK) + (PKLB)/2 - {GCA (PK) + GCA (LB)}/2.

The hererosis measured on the crossbreeds to determine the levels of inheritance or improvement. Heterosis was calculated on percentage of mid-parents: {F1 – [(P1 +

P2)/2] / [(P1 + P2) / 2] x 100} using the mean, where F1 = the first filial and P1 or P2 is a parent in diallel and reciprocal crosses (Razuki & Al-Shaheen, 2011). Line heterosis presents the effect of specific line on the offspring (F1 offspring) performance. According to Saadey et al (2008), the formula for heterosis explained and calculated as follow: where p = number of parents, h_{ij} = specific heterosis obtained by crossing breed I and j; h = average heterosis calculated by 50% mean of sire + 50% mean of dam. hi = {h – [(p-1 / p-2)/ (p-1 / p-2) x 100]}. In the current study, the formula for White Leghorn (WL) sire and Naked neck (NN) dam was as follow: H% = WLNN – ((0.5WL + 0.5NN)/ (0.5WL + 0.5NN)) x 100. These were the means of all crosses without purebred parental lines and y^{-}p the overall mean of all crosses with parents. In the 4 x 4 diallel group, y^{-*} , was a mean of four (4) purebred group and y^{-}p was also be mean of is a mean of 6 crossbred groups and 6 reciprocal crosses. Reciprocal effect (r_{ij}) for the combination i x j was calculated as $r_{ij} = (y_{ij} – y_{ji})/2$.

Maternal effect (M_j) was calculated as the mean deviation of progeny for a particular sire line (i.e. mj = (y.i – yi), where y.i = mean of dam line and yi mean of sire line. Direct genetic effects (v_i) represent the effect of the specific line on the progeny performance excluding the overall mean and means of sires and dams line {i.e., v_i = [y_{ii}-yp –m_j]}, where, v_i = direct genetic effect for line i, y_{ii} = mean parental line i; y_p = overall mean of the p entries on leading diagonal in the diallel (Razuki & Al-Shaheen, 2011).

The improvement vigour on crossbred poultry is similar to heterosis and is known as hybrid vigour. Due to the variation on phenotypic body structures and egg production between the breed the hybrid vigour was also expressed using the following formula:

$$\text{Hybrid vigour} = \text{Hybrid (\%)} = \frac{(Crossbred\ mean - purebred\ mean)}{Purebred\ mean}\ x\ 100$$

The formula for Hybrid vigour for F1 genotype from PK and NN present below and same formula was used to all breeds:

$$\text{Hybrid (\%)} = \frac{(PKNN\ mean\ - PK\ mean)}{PK\ mean}\ x\ 100$$

3.5.2.4 Phase 2: Genetic analysis of F1 offspring

The genetic analysis data was analysed statistically to find the fixed effect on sire genotype, dam genotype and their interactions using the general linear model of statistical analysis system (IBM Corporation, 2017). Multiple comparison and significant difference of means were separated using Scheffe`s multiple comparison test. The following model was used:

$$Y_{hijk} = \mu + a_h + p_{ii} + g_i + g_j + m_j + c_{ij} + r_{ij} + e_{hijk}$$

Where:

Y_{hijk} = the k^{th} observation on the individual chicken produced from the i^{th} breed of sire and the j^{th} breed of dam in the h^{th} type of breeding (purebred, crossbreed and reciprocal cross).

μ = the overall mean,

a_h = an effect common to progeny of the h^{th} type of breeding,

P_{ii} = the effect common to all progeny of a mating between of the i^{th} breed of sire and the i^{th} breed of dam,

$g_i(g_j)$ = the effect of general combining ability (GCA) of the $i^{th}(j^{th})$ breed,

m_j = the effect of maternal ability (MA) for the j^{th} breed of dam,

c_{ij} = the effect of specific combining ability (SCA) of the ij^{th} or cross ($i \neq j$),

r_{ij} = the sex-linked or reciprocal effect (SL) of the ij^{th} cross ($i \neq j$) and

e_{hijk} = random error

This model was used to test significance and to estimate the effects of heterosis, purebreds, maternal, GCA, SCA and SL by applying the restrictions model in SAS/STAT 14.3 user guide (SAS, 2017).

The analysis genetic heritability on eggs quality data was perform statistically to determine how genes from particular sire crossed with dam from other breed effect on offspring and egg quality of developed genotype. The interactions was tested using the general linear model of statistical analysis system (IBM Corporation, 2017). Multiple comparison and significant difference of means were separated using Scheffe`s multiple comparison test. The following model used to analyse heritability on eggs:

$$Y_{hijk} = \mu + m_j + c_{ij} + e_{hijk}$$

Where:

Y_{hijk} = the kth observation on produced egg quality from progeny resulted from the ith breed of sire and the jth breed of dam in the hth type of breeding (purebred, crossbreed and reciprocal cross).

μ = the overall mean egg quality per F1 breed,

m_j = the effect of maternal ability (MA) for the jth sire or dam on egg characteristics,

c_{ij} = the effect of specific combining ability (SCA) of the ijth or cross ($i \neq j$),

e_{hijk} = random error

This model used to test significance difference and to estimate the effects of heterosis, purebreds, maternal, GCA, SCA and SL by applying the restrictions. The combine egg production ability was calculated by method used applied by (Sh et al., 2012).

3.6 USE OF FEED COST ENVISAGE ECONOMIC BENEFIT FROM CROSSBREEDING

The current study used 4 x 4 diallel to produce crossbreed chicken that is cost effective on rearing and on egg production. Feed cost was the only economic factors that was measured on this study to determine the economic efficiency factor during rearing and egg production. Under the normal commercial egg laying farming, feed contributed 80% of the overall cost. Other economic parameters were excluded on this study due to small-scale of chickens in research and lack of standard fixed cost and variable cost used in research facilities.

Rearing parameters involve the measures of weekly: feed intake, weight gain and feed conversion ratio (FCR). The economic efficiency factor (EEF) for rearing was calculated by multiplying FCR by cost of feed per kg.

Economic Efficiency Factor for rearing

Step 1: FCR = Feed Intake / Weight gain

Step 2: Rearing EEF = FCR x Feed cost on Rand per kg

Egg grading is one of the measures that was used for productivity. Therefore, eggs were collected, recorded per breed and graded according to their breed to determine number of eggs produced per size and per breed. The eggs were graded ranging from small, medium, large, extra-large and jumbo for economic efficiency determination. The economic efficiency during laying period was calculated by graded eggs according to categories which were priced by consideration of actual feed cost.

Economic Efficiency Factor for Egg production

Step 1: Egg FCR = Feed intake in kg / Dozen weight in kg

Step 2: EEF on Egg = Egg FCR x Feed cost on Rand per kg

3.7 ETHICAL PROCESS OF THE STUDY

The study was conducted according to policies and standard operating procedures of the Agricultural Research Council (ARC) and University of South Africa. The study was ethically approved by ARC (Reference number APIEC 15/033), and the UNISA, College of Agriculture and Environmental Sciences (reference number 2014/CAES/064) research ethics committees.

CHAPTER 4

4 RESULTS

4.1 INTRODUCTION

The stud breeder farmers, who practice the inbreeding often select an individual chicken (male and female) based on its performance, qualities of characteristics and set breed or farming goals. Even when traits are medium to highly heritable, an individual animal`s own value is most important. The value of layers cannot be based on the growth performance only. Therefore, in the current study first selection was based on growth performance variables, feed conversion ratio, economic efficiency cost of layers from day 1 to 18 weeks of age. The second selection was based on average feed intake during laying, egg production percentage, egg quality traits, consumer preference on egg products, and egg grading weight since are used for the economic efficiency factor.

4.2 THE BODY WEIGHT

Figure 4.1 Shows the body weight mean and standard error of combine sex per breed at the age of 18 weeks. The White Leghorn parent recorded the lowest body weight of 1321 g, offspring slight improve weight to 1479 g. Potchefstroom Koekoek parent attain 2079 g, offspring the highest weight 2166 g. The mean difference of 845 g observed between the body weight of White Leghorn pure breeds and Potchefstroom Koekoek dual-purpose breed at significant of ($p < 0.0001$). On the crossbreeds, WLLB recorded the lowest body weight of 1628 g, highest weight by PKLB 2079 g. The mean difference of 451 g was observed between the two crossbreeds with no significant difference at ($p < 0.05$).

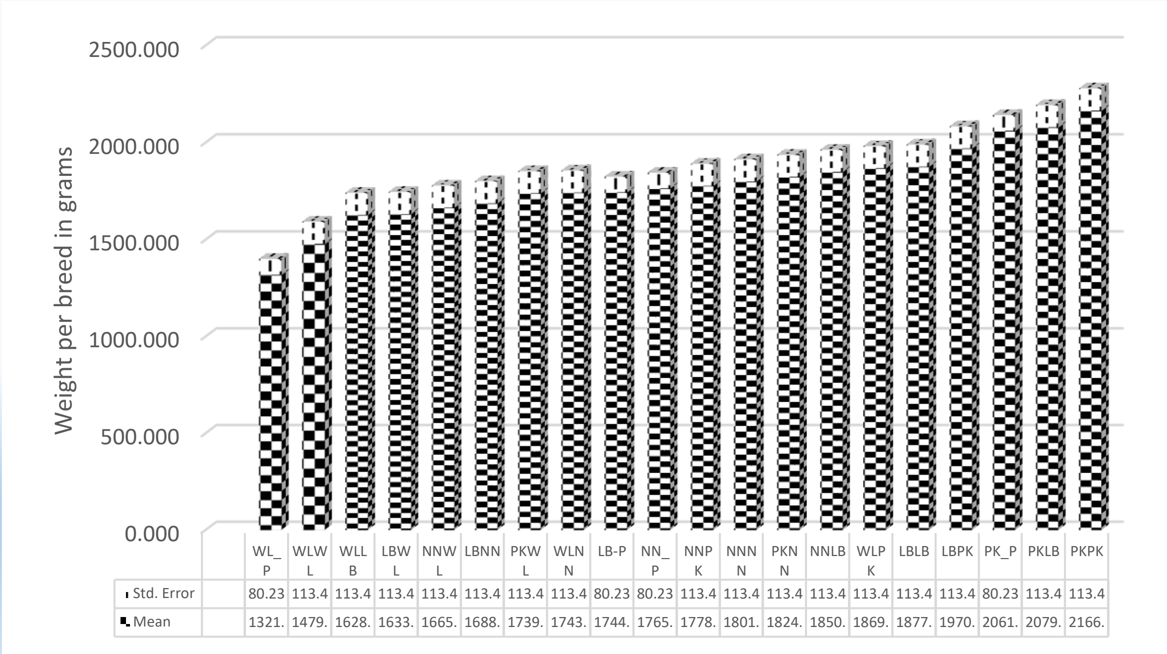


Figure 4.1 Mean body weight of combine sex per breed at the age of 18 weeks.

Figure 4.2 shows the body weight of Naked neck chicken breed and its pure breed and crossbreed offspring at the age of 18 weeks. The mean body weights are present according to the sex of the chickens. The body weight for NN differ significantly with two pure parent breeds, WL at ($p < 0.041$) and Potchefstroom at ($p < 0.010$). There was no significant difference between NN and its offspring from crossbreed or pure breed.

The mean body weight of chicken breeds was organised from the smallest body weight to biggest body weight in the table. The body weight means between the breed groups were highly significant ($p < 0.0001$). The analysis within the breeds did not yield any significant level that shows uniform body weight within breeds.

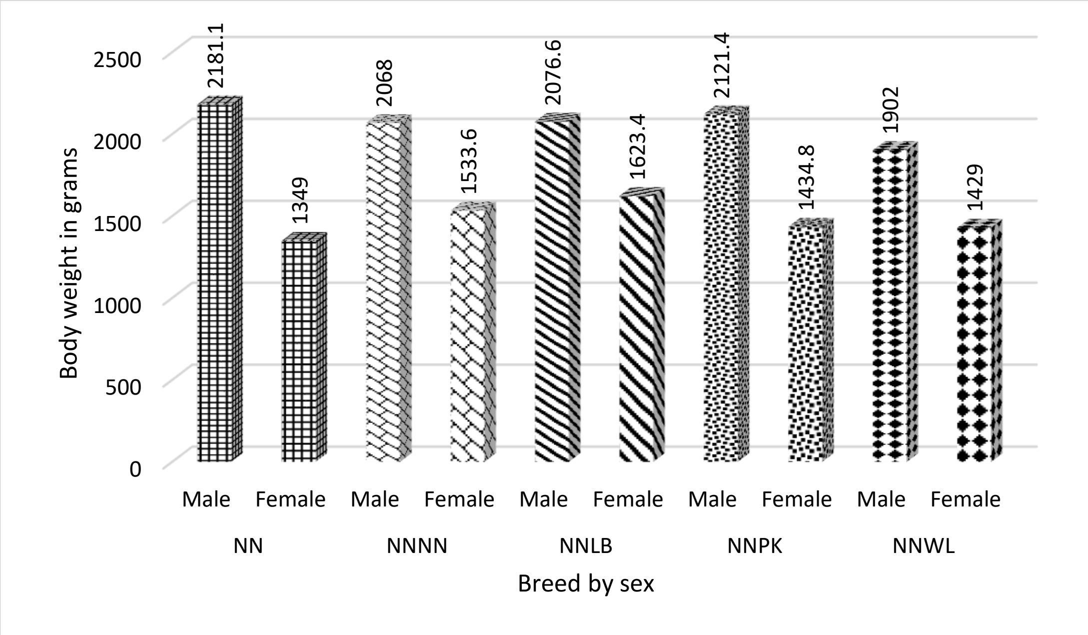


Figure 4.2: Body weight for Naked neck breed and its F1 offspring

Lohmann Brown is one of the reputable layer breed used for egg production business across the world. Figure 4.3 shows mean body weight of LB pure breed and its offspring from pure breeding and crossbreeding. The LBPK males obtained body weight of 2 273 g while females had 1 669 g for body weight. The lowest male mean body weight (1 926 g) was obtained by LBWL. There was low significant difference ($p < 0.044$) between the body weight of LBPK and LBWL

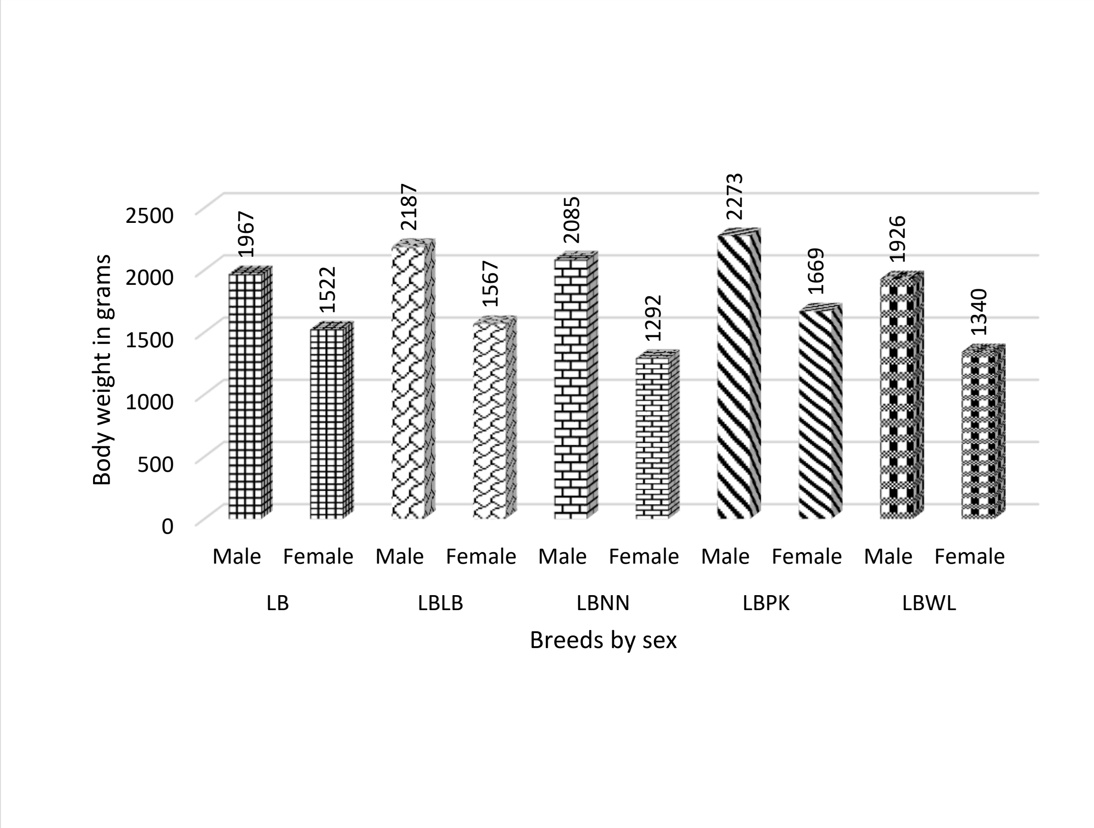


Figure 4.3: Body weight for Lohmann Brown and its F1 offspring

The parent male (PK) had the highest body weight (2 561 g) compared to its F1 offspring (Figure 4.3) and the body weight differed significantly at $p < 0.0001$) between PKNN and PKWL. However, the female parent had second lowest body weight (1 562 g) after PKWL crossbreed (1 460g). The PK pure breed female F1 offspring recorded the highest body weight (1 966 g). The PKPK male F1 offspring recorded lower body weight (2 367g) than its parent (2 561g) and F1 PKLB crossbreed (2 434g) although it did not differ significantly. Figure 4.4 shows the body weight of Potchefstroom Koekoek and its F1 offspring from pure breeding and crossbreeding.

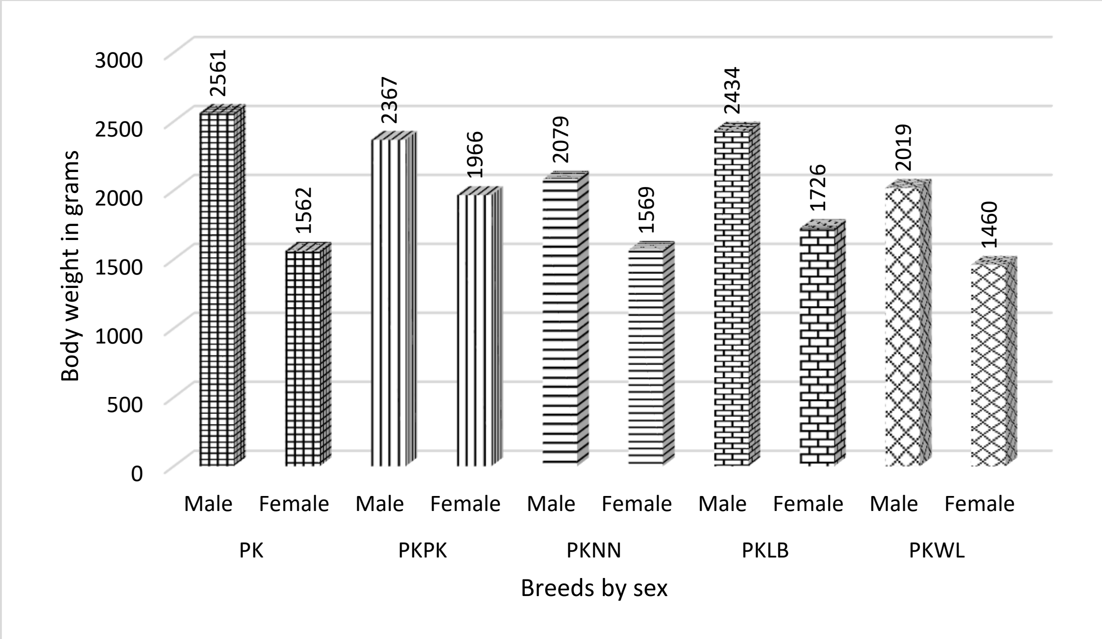


Figure 4.4: Body weight for Potchefstroom Koekoek and its F1 offspring

The male and female parent of White Leghorn showed the lowest mean body weight when compared to other pure breeds (Figure 4.2; 4.3 and 4.4 above) and its offspring from pure breeding and crossbreeding. Figure 4.5 shows the body weight of White Leghorn and its offspring from pure breeding and crossbreeding. The combined sex body weights of WL was highly significant to three pure breeds NN, LB, and PK at ($p < 0.0001$), and its offspring WLNN ($p < 0.003$), WLLB ($p < 0.028$) and WLPK (p 0 < 0001).

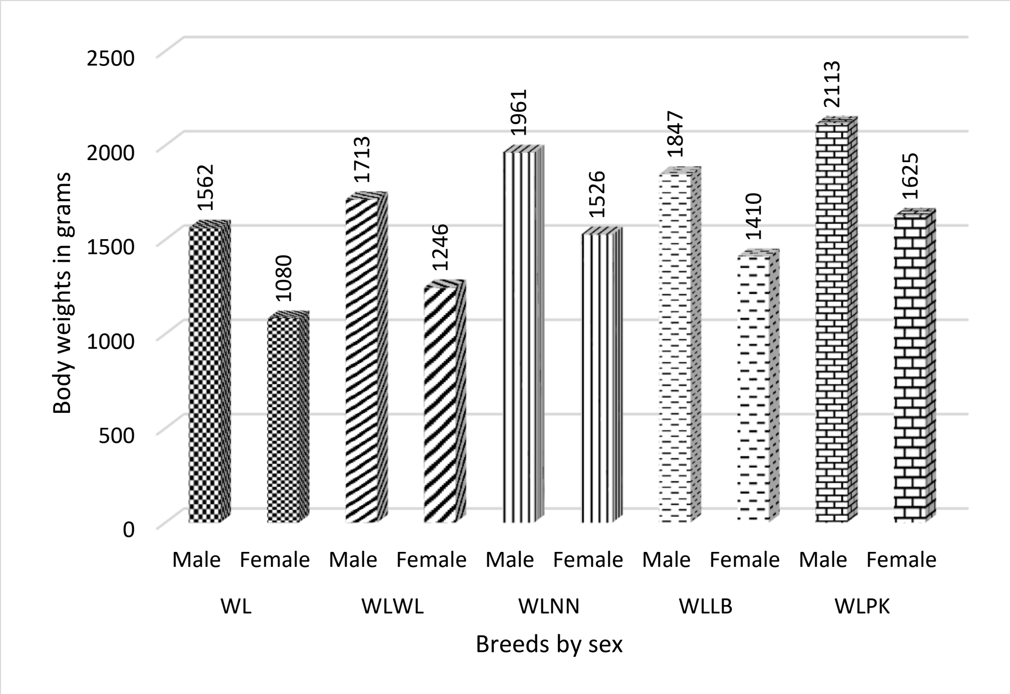


Figure 4.5: Body weight for White Leghorn and its F1 offspring

The pair mean body weight of breeds was further compared between the breeds. The results revealed significance difference on the body weight across the pure breeds and crossbreeds. The parent indigenous chickens Naked neck differed significantly with PKLB at ($p < 0.025$). The body weight for LB differed significantly with PK ($p < 0.006$), PKPK ($p < 0.003$), and PKLB ($p < 0.017$). The body weight of PK differed significantly among NN ($p < 0.010$), LB ($p < 0.006$), NNPK ($p < 0.042$), NNWL ($p < 0.005$), LBNN ($p < 0.008$), LBWL ($p < 0.002$), PKWL ($p < 0.021$), WLWL ($p < 0.0001$), WLNN ($p < 0.023$) and WLLB ($p < 0.002$).

The South African dual-purpose breed Potchefstroom Koekoek differed significantly to other pure breeds NN ($p < 0.010$), LB ($p < 0.006$) and WL ($p < 0.0001$). The PK continued to differ significantly with other crossbreeds as follows; NNPK ($p < 0.042$), WLNN ($p < 0.023$), PKWL ($p < 0.021$), LBNN ($p < 0.008$), LB ($p < 0.006$), NNWL ($p < 0.005$), LBWL and WLLB ($p < 0.002$) and WLWL ($p < 0.0001$).

The White Leghorn had smallest body weight and differed significantly with LBWL ($p < 0.026$), WLLB ($p < 0.028$), NNWL ($p < 0.014$), LBNN ($p < 0.009$), PKWL and WLNN ($p < 0.003$), NNNN and NNPK ($p < 0.001$), NNLB, LBLB, LBPK, PKPK, PKNN, and WLPK ($p < 0.0001$).

The pure breed offspring like their parents continued to show significant difference on the body weight. The WLWL differed significantly to NNNN ($p < 0.046$), LBLB ($p < 0.014$) and PKPK ($p < 0.000$). There was no significant difference between NNNN and LBLB, PKPK and LBLB, while PKPK differed significantly to NNNN at ($p < 0.024$). The WLWL continued to differ significantly to the crossbreeds as follows; PKNN ($p < 0.033$), NNLB ($p < 0.022$), WLPK ($p < 0.016$), LBPK ($p < 0.002$) and PKLB ($p < 0.0001$). The PKPK body weight was heavier compared to many crossbreeds by showing significant difference as follow; PKNN ($p < 0.034$), NNPK ($p < 0.016$), WLNN ($p < 0.009$), PKWL ($p < 0.008$), LBNN and NNLB ($p < 0.003$), NNWL ($p < 0.002$), LBWL and WLLB ($p < 0.001$).

The crossbreeding between PK and LB had positive effect on the body weight of its crossbreed offspring whereby they differed significantly to other crossbreed offspring. The body weight for LBPK differed significantly with LBWL ($p < 0.037$) and WLLB ($p < 0.034$). The PKLB was the heaviest crossbreed offspring and it differed significantly to NN, LB, WL and WLWL pure breeds as indicated above. The PKLB continued to differ significantly to other crossbreeds as follows; WLNN ($p < 0.037$), LBNN ($p < 0.015$), NNWL ($p < 0.010$), LBWL ($p < 0.006$), WLLB ($p < 0.005$).

4.3 FEED CONSUMPTION

Figure 4.6 show the average cumulative feed consumption per breed from day old up to 18 weeks of age. The LBNN crossbreed abating the lowest cumulative feed consumption of 10,868 kg, NNPK crossbreed was the highest with 17, 442 kg. On the pure breeds, White Leghorn and Naked neck were at the closest range at 12,591 and 12,644 kg respectively, while PK had attained cumulative feed of 14,266 kg.

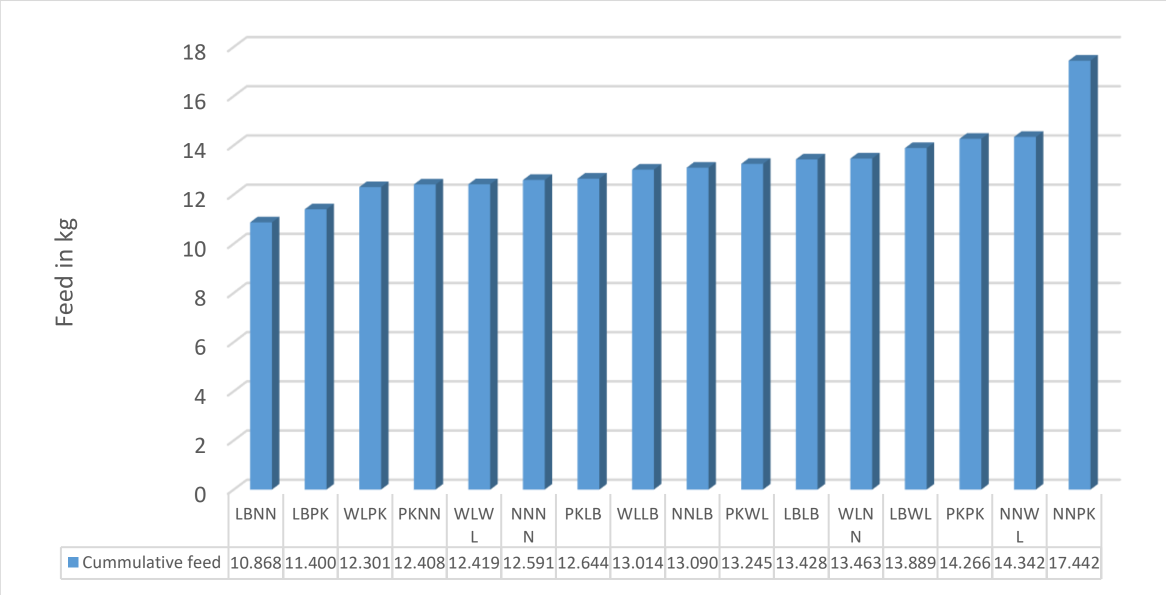


Figure 4.6: Cumulative feed consumption per breed from day old up to 18 weeks age.

The effects of crossbreed on feed consumption presented on the separate figures of pure breeds and their crossbreed offspring. The LB had the highest feed consumption (13.428 kg) cumulative feed intake while NN consumed (12.591 kg). The LBNN crossbreed had the lowest cumulative feed intake of (10.868 kg) compared to NNLB with (13.090 kg) were significant ($p < 0.05$).

The PK consumed more feed (14.266 kg) than NNNN with (12.591 kg). The PKNN consumed more feed than any other breed in the study and it was significant ($p < 0.05$) to all breeds. The pure breeds NN and WL, consumed similar amount of feed with slight difference of 0,172 kg. The NNWL consumed the highest feed amount (14.342 kg) while WLNN consumed second highest feed of (13.463 kg) and were significant ($p < 0.05$).

The PK offspring consumed more feed amount (14,266) than LB with the difference of 0.838 kg, but not significant ($p > 0.05$). Similar amount of feed consumed was obtained by PKLB with 14.266 kg which was significant ($p < 0.05$) to LBPK with difference of 1.244 kg at the age of 18 weeks. The WL consumed 12.419 kg which was lower compared to LB with consumption of 13.428 kg. The LBWL crossbreed consumed almost similar feed to LB offspring. The WL had total consumption of 12.419 kg which was 0.595 kg less than overall consumption of WLLB crossbreed and were not significant ($p > 0.05$). The WL consumed 12.419 kg while PK consumed 14.266 kg at 18 weeks of age and were significant ($p < 0.05$). The cumulative feed consumption between WL and WLPK differed with 0.118 kg and it was not significant ($p > 0.05$).

4.4 FEED COST ON ECONOMIC FACTOR FOR F1 OFFSPRING DURING GROWTH PHASE

Figure 4.13 shows the average feed cost per chicken per breed at the age of 18 weeks. The most economic efficient feed cost used to raise chicken breeds from day old chicks to 18 weeks in this study were LBPK at R38.79, followed by PKLB at R40.76, LBNN at R43.16, WLPK at R44.13 and PKPK at R44.16, and they all differed significantly at ($p < 0.011$). The three F1 offspring showed an expensive economic efficiency factor of the following; NNPK at R71.83, significant to NNWL at R57.74 and LBWL at R57.02 this two were not significant ($p > 0.05$).

The performed correlation between cumulative feed intakes, weight gain, feed conversion ratio (FCR) and economic efficiency factor (EEF) yielded negative and positive correlations. The strong correlation relationship of ($r = 0.998$) with significant of ($p < 0.0001$) was observe between average body weight at 18 weeks of age and body weight gain. Negative correlation of ($r = -0.701$) was observed between feed conversion ratio and economic efficiency factor and were significant ($p < 0.002$). The results further revealed negative correlation $r = -0.697$ at significant level of ($p < 0.003$) between weight gain and FCR. Cumulative feed intake at 18 weeks of age revealed strong relationships to FCR ($r = 0.813$) at significant ($p < 0.0001$) and EEF ($r = 0.814$) at ($p < 0.0001$).

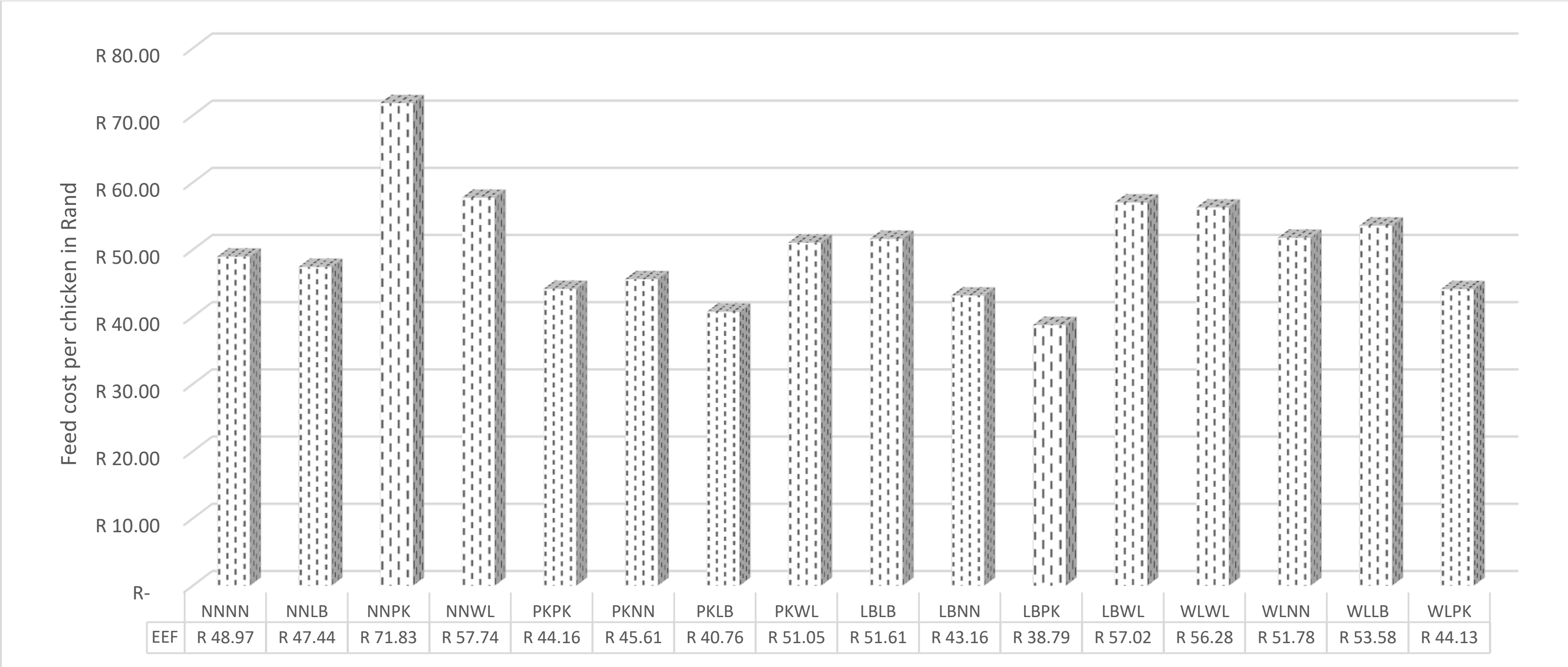


Figure 4.7: Average economic efficiency factor of feed per chicken per breed from day old to 18 weeks of age

4.5 PHENOTYPIC CHARACTERISTICS

4.5.1 Phenotypic characteristics of body structures of parent and F1 offspring at 18 weeks age

Table 4.1 shows the measured phenotypic characteristics of body structure for pure parent pure breeds and their offspring. The body weight for Naked neck was 2 187 g higher than LB 1 967 g. The body length for Naked neck was 382 mm, was the only variable shorter than Lohmann Brown with 396 mm and the differences were significant ($p < 0.006$). The Naked neck showed wider wingspan (526 mm) than Lohmann Brown (495 mm) without significant difference. The broader chest circumference of (347 mm) was obtained by Naked neck, while Lohmann Brown attained 323 mm. The longer shank length was obtained by Naked neck (104 mm) compared to Lohmann Brown (95 mm), with a significantly difference at level ($p < 0.028$). Appendix D, E and F presents the significances of the multivariate differences between the means of the body structure for further interpretation.

The local dual-purpose breed (PK) dominated its offspring when crossed with LB on all the phenotypic body structures. Potchefstroom Koekoek cocks had the higher body weight, body length ($p < 0.019$), wingspan means compared to the Naked neck cocks. Surprisingly, both males had similar mean of 347 mm on chest circumference. Naked neck had higher mean of the shank length than Potchefstroom Koekoek but it was not significant ($p > 0.05$). Different results were observed concerning females whereby Naked neck had higher mean on body weight and length at significant level of ($p < 0.019$) with no significant level of the chest circumference. Potchefstroom Koekoek had big body structures than White Leghorn. The PKWL offspring had higher variables of phenotypic body structures compared to White Leghorn with high significant difference ($p < 0.0001$) on body weight and length shank, least significant of ($p < 0.049$) on body length and no significant on chest circumference. The crossbred between PK x LB resulted to heavier body weight and longer body length that was higher than initial pair weight of their parents without significant difference ($p > 0.05$). The PK maintained the same trend while WL pure offspring showed significantly higher wingspan compared to all other breeds.

Table 4.1: Phenotypic body structures for combine pure breeds and their offspring at 18 weeks of age

Breed	Body weight (g)		Body length (mm)		Wing span (mm)		Chest circumference (mm)		Shank length (mm)	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
WL	1 321	264.15	360	20.16	452	32.38	288	17.70	82	9.80
WLWL	1 480	286.92	362	25.69	395	127.38	275	89.47	85	4.42
WLLB	1 629	279.07	373	61.60	440	70.66	297	23.58	97	36.72
WLNN	1 480	286.92	362	25.69	395	127.38	275	89.47	85	4.42
WLPK	1 869	318.29	386	31.54	456	32.94	327	36.61	93	10.14
PK	2 062	542.41	385	35.22	500	41.63	321	38.45	92	9.65
PKPK	2 166	283.46	393	26.40	473	34.61	353	35.99	98	14.19
PKLB	2 080	448.73	413	36.25	500	34.21	342	36.33	91	31.56
PKNN	1 824	306.30	396	48.91	441	38.22	328	26.65	91	3.24
PKWL	1 740	333.76	367	14.98	455	30.83	311	38.52	100	13.32
LB	1 744	253.99	381	27.19	468	38.20	311	18.02	86	11.26
LBLB	1 877	349.82	385	16.71	464	31.70	342	41.17	81	25.76
LBNN	1 688	424.19	388	18.44	465	47.75	324	54.29	84	4.69
LBPK	1 971	383.06	382	20.97	478	50.41	364	65.95	93	14.18
LBWL	1 633	335,40	354	39,26	428	47,04	304	23,41	96	11,16
NN	1 765	468.93	405	27.98	491	42.45	322	29.50	94	10.68
NNLB	1 850	268.52	396	25.14	475	31.25	347	42.93	99	15.50
NNNN	1 801	294.80	379	20.75	465	30.87	349	55.23	88	4.25
NNPK	1 778	384.54	394	34.04	482	39.51	330	52.74	85	9.00
NNWL	1 666	288.30	383	42.84	439	56.86	318	33.60	96	12.80

The phenotypic body structures revealed that WL had inferior body structures compared to Naked neck. The inferior body weight of White Leghorn resulted to significant difference to all pure breeds and some crossbreeds ($p < 0.05$). The WL pure breed also maintained the highly significant ($p < 0.001$) chest circumference compared to other breeds. The body weight, body length, wingspan, chest circumference and shank circumference revealed high level of significant ($p < 0.0001$). There was significant difference on the body length at ($p < 0.0014$) and chest circumference ($p < 0.027$) between WL and LB breeds. The LBWL obtained 24% body weight higher than WL and 25% less than LB and were similar compared to two parents.

All measured phenotypic body structure multivariable showed high significant ($p < 0.0001$) effects on breed, sex and combine breeds per sex. The combine body weight between pure breeding and crossbreeding differed significantly ($p < 0.0001$). The mean difference between crossbreeding and reciprocal was -100 g and was not significant. The outcome of the effects of phenotypic sum and mean square showed high significant level ($p < 0.0001$) on the effects between the variables. The interactions between breed and leg shank length showed no significant difference between the breeds. The interception between breeding type (pure breeding and crossbreeding) was also tested as the fixed effect and results did not differ between the crossbreed and pure-breed offspring.

4.5.2 Phenotypic characteristics for the head of genotypes

The beak colour, eye colour, comb type and ear colour were not analysed because they were similar across the breeds. Table 4.2 shows the means of measured phenotypic head variables per breed pair and per sex. Exploring the comb length of the pure breed males, LB mean stand at 73.40 mm, NN at 71.70 mm, PK at 75.80 mm was not significant at ($p > 0.05$) and WL at 102.40 mm. The comb for the pure breeds were as follows; NN males 71.70 mm, NN females, 31.80 mm, LB males 73.40 mm and LB females 28.10 mm and were not significant.

Table 4.2: Phenotypic characteristics of head variables per breed per sex

Breed	Sex	Comb length (mm)		Comb Height (mm)		Wattles Length (mm)		Wattles Width (mm)	
		Mean	Std. Error	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error
	M	73.40	4.67	34.10	3.04	36,40	1.90	31.30	2.07
LB	F	28.10	4.67	25.50	3.04	23,90	1.90	12.70	2.07
	M	78.20	6.61	41.00	4.30	42,40	2.69	42.40	2.93
LBLB	F	30.20	6.61	14.60	4.30	17,00	2.69	23.40	2.93
	M	79.60	6.61	36.00	4.30	44,00	2.69	44.80	2.93
LBNN	F	37.60	6.61	17.00	4.30	21,00	2.69	23.60	2.93
	M	91.00	6.61	48.60	4.30	49,20	2.69	49.00	2.93
LBPK	F	23.00	6.61	15.00	4.30	16,00	2.69	20.60	2.93
	M	104.40	6.61	52.60	4.30	51,80	2.69	53.20	2.93
LBWL	F	42.60	6.61	20.40	4.30	18,80	2.69	27.20	2.93
	M	71.70	4.67	33.00	3.04	32,40	1.90	36.00	2.07
NN	F	31.80	4.67	11.40	3.04	18,80	1.90	10.30	2.07
	M	87.00	6.61	47.80	4.30	48,80	2.69	49.80	2.93
NNLB	F	48.00	6.61	22.60	4.30	26,40	2.69	28.00	2.93
	M	79.80	6.61	40.40	4.30	45,00	2.69	45.20	2.93
NNNN	F	37.20	6.61	19.00	4.30	21,20	2.69	27.00	2.93
	M	77.40	6.61	36.20	4.30	41,80	2.69	38.20	2.93
NNPK	F	39.80	6.61	16.00	4.30	21,60	2.69	25.40	2.93
	M	109.20	6.61	54.60	4.30	52,00	2.69	50.20	2.93
NNWL	F	44.00	6.61	21.80	4.30	21,60	2.69	23.60	2.93
	M	75.80	4.67	36.20	3.04	31,50	1.90	35.50	2.07
PK	F	29.20	4.67	10.90	3.04	22,10	1.90	12.10	2.07
	M	90.00	6.61	36.00	4.30	50,40	2.69	44.20	2.93
PKLB	F	38.20	6.61	16.20	4.30	16,40	2.69	23.80	2.93
	M	75.80	6.61	31.80	4.30	44,20	2.69	40.20	2.93
PKNN	F	43.80	6.61	16.80	4.30	26,00	2.69	23.60	2.93
	M	74.60	6.61	40.40	4.30	44,20	2.69	45.00	2.93
PKPK	F	34.40	6.61	15.00	4.30	14,60	2.69	21.20	2.93
	M	85.60	6.61	57.40	4.30	51,40	2.69	47.80	2.93
PKWL	F	42.20	6.61	21.40	4.30	16,00	2.69	23.00	2.93
	M	102.40	4.67	54.10	3.04	33,90	1.90	44.70	2.07
WL	F	25.80	4.67	12.80	3.04	14,80	1.90	45.00	2.07
	M	84.60	6.61	50.60	4.30	42,80	2.69	30.00	2.93
WLLB	F	34.60	6.61	13.40	4.30	15,00	2.69	17.60	2.93
	M	99.20	6.61	50.00	4.30	57,40	2.69	48.20	2.93
WLNN	F	42.00	6.61	20.00	4.30	18,00	2.69	18.80	2.93
	M	101.20	6.61	55.80	4.30	50,80	2.69	49.20	2.93
WLPK	F	35.20	6.61	16.40	4.30	14,60	2.69	22.40	2.93
	M	71.00	6.61	47.40	4.30	49,40	2.69	48.40	2.93
WLWL	F	47.20	6.61	28.80	4.30	19,20	2.69	22.00	2.93

Both male and female NNLB had significantly higher mean, compared to their parents (NN x LB). The NNLB differed significantly with LB at ($p < 0.004$) level, with NN at ($p < 0.006$) level and LBLB at ($p < 0.045$). The outcome for heterosis revealed that NNLB male comb mean was 21.34 % higher than NN. The NNLB female comb mean was 50.94% higher than NN. The outcome for heterosis revealed that LBNN males comb was 8.45% higher than LB. The LBNN female comb was 33.81% higher than LB. Heterosis for LBNN males was 35.16% from LB pure males, while LBNN female had suppression of -27.60% without significant difference ($p > 0.05$). The heterosis for overall mean LBNN was 11.45% while NNLB value was two times higher (22.74%).

4.5.3 Phenotypic characteristics of feathers for pure breeds and F1 crossbreeds

Figure 4.8 shows the range of feather colours observed from Naked neck during phenotypic characteristics study. The original male parents had four range of colours while females had five range of colours. The offspring of NN from pure-breeding did not have same colours, instead the number of colours increase by other four colours

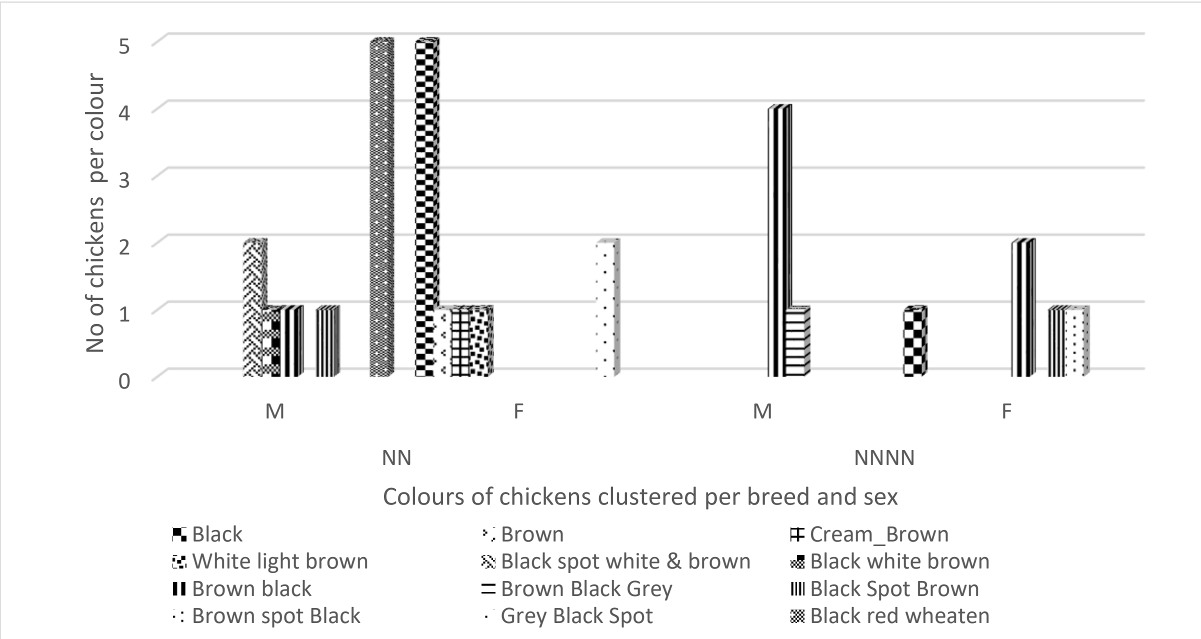


Figure 4.8: The feather colours of Naked neck and its pure-breed offspring Change colours of the following to patterns:

The Lohmann Brown layers are built from the combination of four great parent breed. The commercial layers hatched with two different colours female are brown while males came with white in colour. As they grew females remained white and males developed some brown spot feathers in their wing feathers. Figure 4.9 shows the phenotypic feather colours of Lohmann Brown parents with its purebred offspring. Lohmann Brown had two main feather colours which resulted to four extra colours that recorded during the phenotypic characteristic study. The five developed colours were cream white, white light brown, white spot brown and brown white colour.

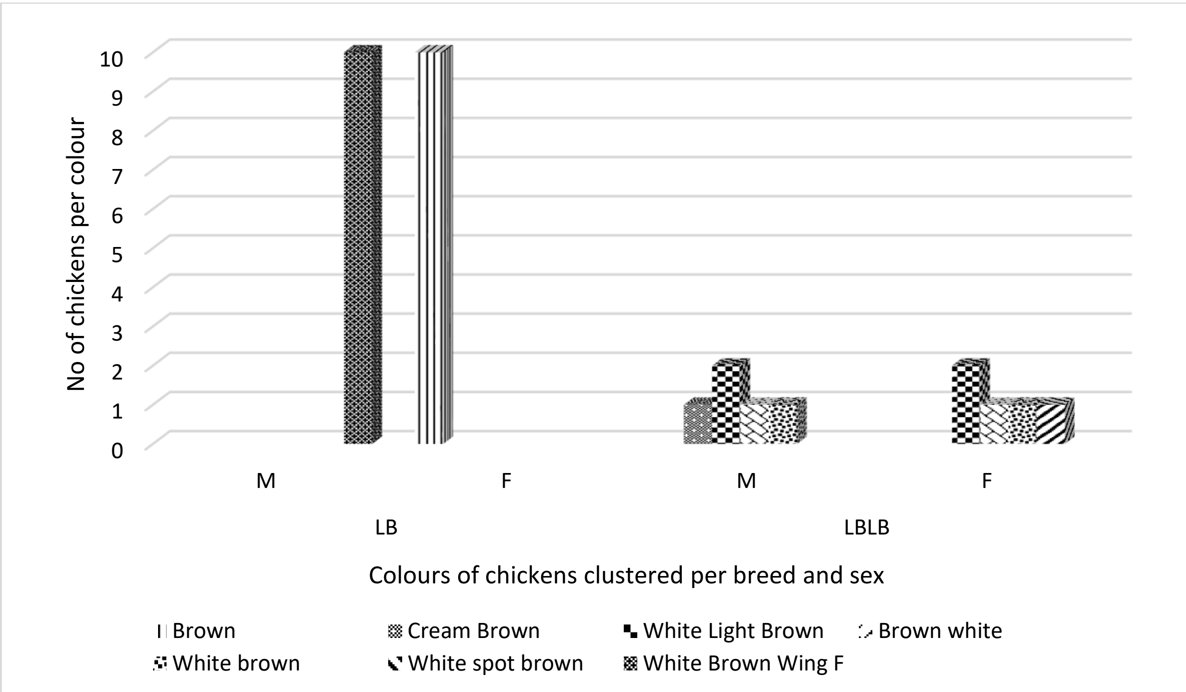


Figure 4.9: The feather colour of Lohmann Brown breed and its purebred offspring.

Picture 4.1 shows the feather colours of LBLB F1 offspring that were attained by breeding brown hens with white and brown cocks. Some of cocks like one pointed with arrow next to the feeder had dominant brown feathers not usual white with spot brown wing feathers. The identified cock inherited the colour of its parent female. The other inheritance of dominant colours of male parent were noticed on some of females like the white light brown on the forefront hen next to the gate.

Picture 4.1: The range of feather colours of Lohmann Brown F1 offspring from pure-breeding

The identification of phenotypic characteristics of F1 crossbreed feather colours start with two completed colours (Naked neck and Lohmann Brown). Naked neck cocks were crossbred with Lohmann Brown hens and the range of feather colours were identified. Figure 4.10 shows the feather colours of Naked neck, Lohmann Brown and their offspring, NNLB and LBNN. Twenty-one colours were recorded from 60 chickens that were coming from four genotypes. The range of feather colours was very high on the offspring of the local indigenous breed (NN) and commercial layer breed (LB). Picture 4.2 shows the feather colours and distribution on NNLB and LBNN F1 offspring. Naked neck seems to have specific gene that dominated the lack of feathers on the neck. All the offspring from NNLB and LBNN had naked neck. The feather colours were fairly distributed to chickens since some of offspring had dominant colours of Lohmann Brown. Two hens with brown white colour showed the inheritance of brown colour from the Lohmann Brown hens.

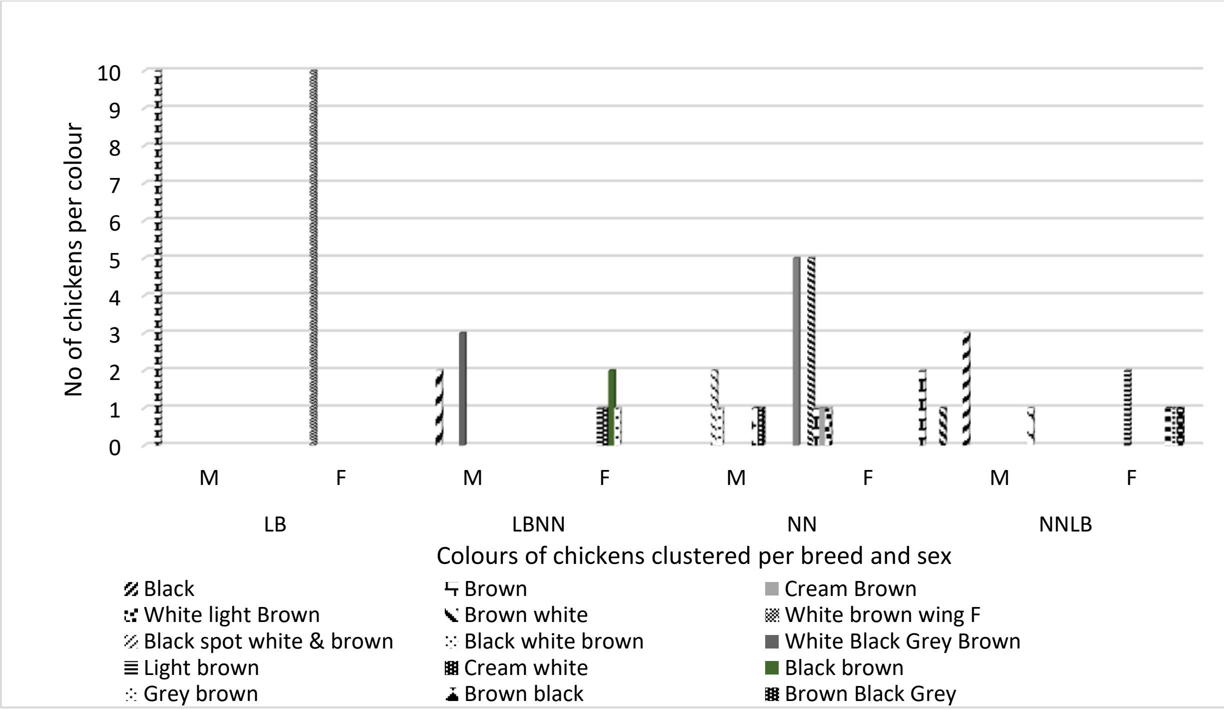


Figure 4.10: The identified feather colours for NN, LB, NNLB and LBNN.

NNLB LBNN

Picture 4.2: Feather colour and distribution on NNLB and LBNN F1 offspring.

Potchefstroom Koekoek breed had one feather colour and was crossbred with Lohmann Brown. Figure 4.11 shows the colours of the LB, PK LBPK and PKLB. PKLB had three feather colours which is PK colour, grey black spot and white light black spot. The LBPK had four colours, PK colours were dominant especially on males, black spot white brown, and PK colour with brown spot neck. Picture 4.3 shows the colours of feathers identified on LBPK F1 offspring.

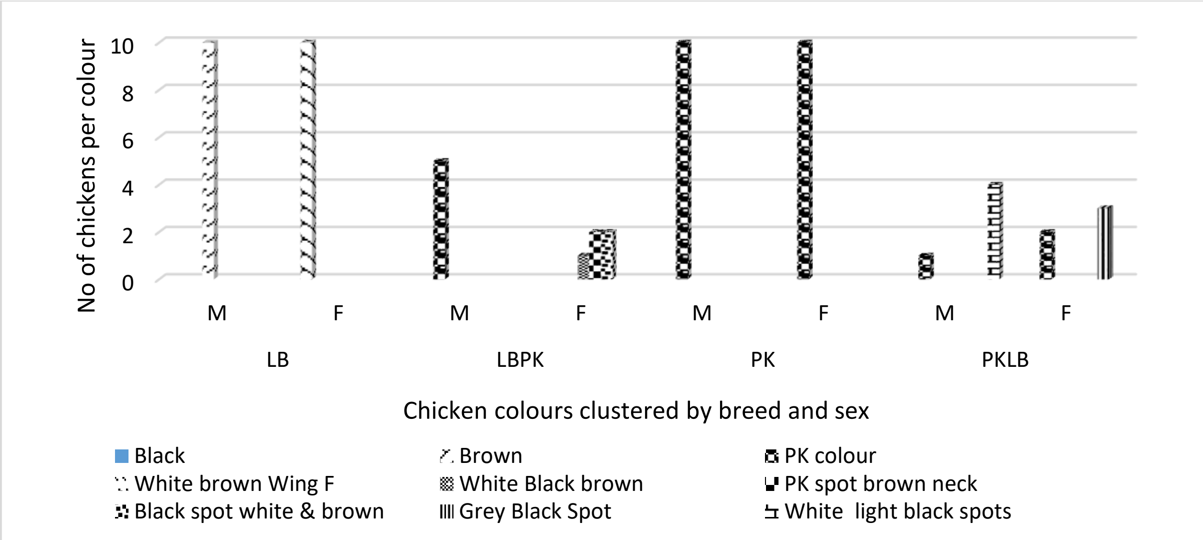


Figure 4.11: The identified feather colours of PK, LB and their F1 offspring

Picture 4.3: Range of feather colours obtain from LBPK F1 offspring

Figure 4.12 shows that White Leghorn male dominated the colour of offspring whereby 80% males that were examined for phenotypic were white with light brown colour while the remaining 20% were white with brown colour. The WLLB females had 80% white colour and 20% brown colour.

Due to two colours found on Lohmann Brown males, four colours discovered on LBWL males with three colours on female. The four colours that were observed on LBWL males were distributed as 20% cream brown, 40% cream white, 20% white brown and 20% white with spot brown and spot black colour. The LBWL females were 60% white, 20% light brown and 20% white with some brown colours.

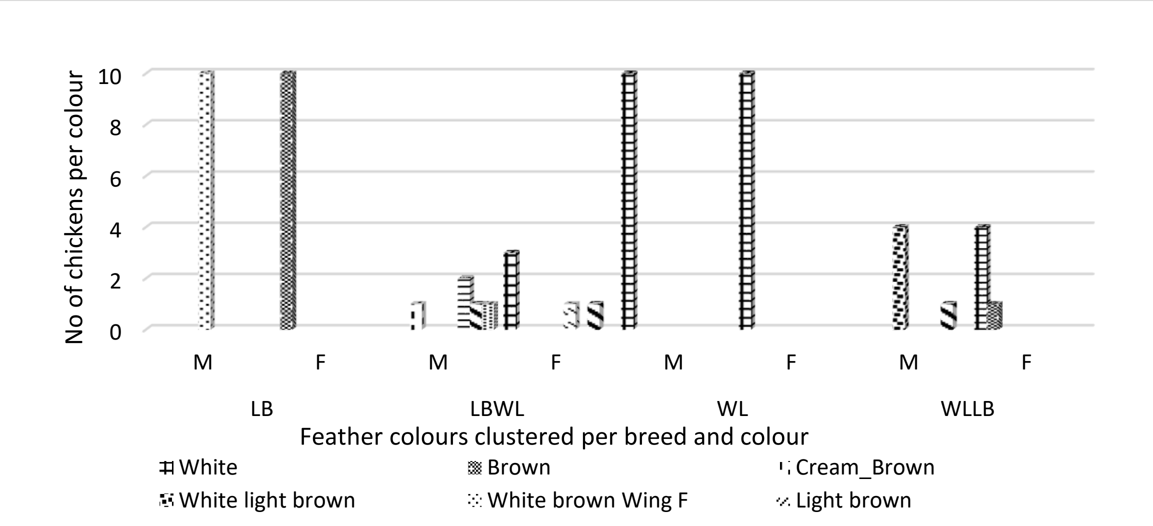


Figure 4.12: Feather colours for LB, WL and their F1 offspring from crossbreeding

The multiple colours (9) breed Naked neck was bred to two-coloured (black and white) breed Potchefstroom Koekoek (Figure 4.13). The crossing of NN sire with PK dam produced only three colours and most of offspring had PK dominated colours. The NNPK male colours were 80% PK colours, 20% grey with brown colour. The NNPK female had 20% black, 80% PK colours.

The PKNN produced chickens with four colours and males recorded 80% PK colours and 20% black red wheaten. Majority of PKNN females scored feather colours as follow; 20% black, 60% PK colours and 20% black spot white and brown. Picture 4.4 shows the feather colours and distribution for NNPK, where PK colours dominated in the flock.

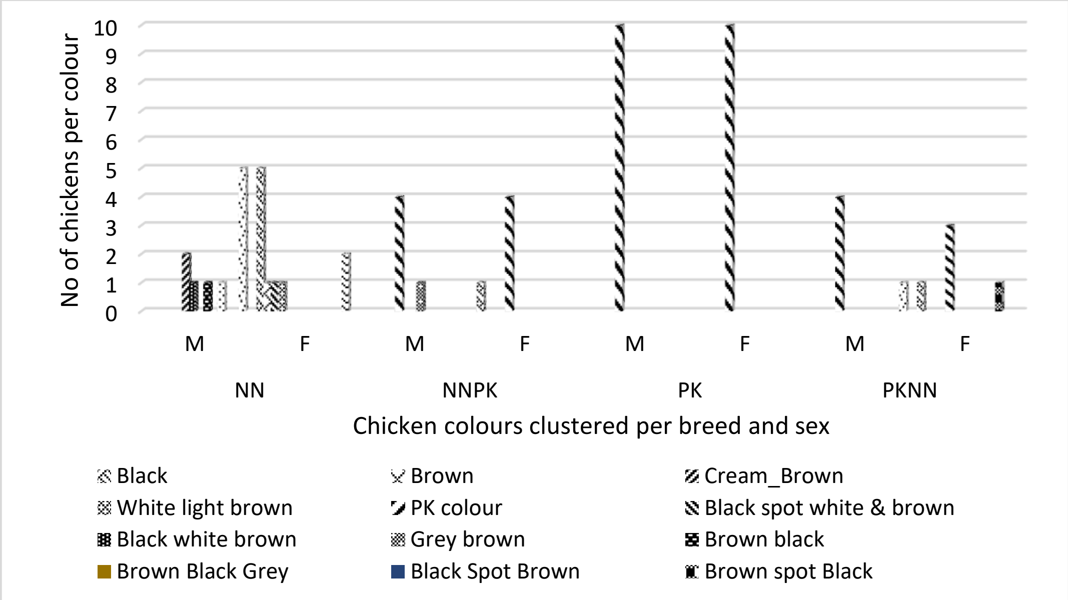


Figure 4.13: Feather colour for NN, PK and their F1 offspring from crossbreeding

Picture 4.4: The feather distribution and colours for NNPK F1 offspring

The pure white coloured breed (WL) was crossbred with multiple feather colour breed, Naked neck. The WLNN had four colours on males and three colours on females. Figure 4.14 shows the feather colours of WL, NN and their F1 offspring.

The WLNN males feather colours were 20% brown, 40% cream-white, 20% white spot brown black and 20% cream light brown. The WLNN females had 40% white, 20% white light brown and 40% grey black spots. Most observed colours of the crossbred were dominated by White Leghorn colour as the interpretation had white and some colour or cream colour.

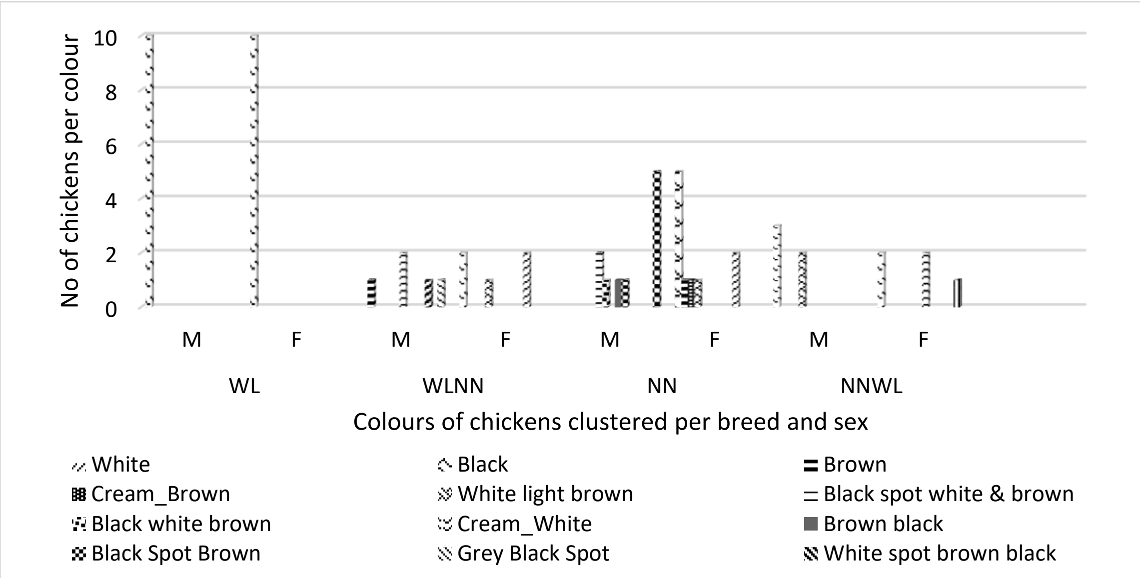


Figure 4.14: Feather colours for WL, NN and their F1 offspring from crossbreeding

Figure 4.15 shows the feather colours of White Leghorn, Potchefstroom Koekoek and their offspring. The WLPK males had 60% cream-white, 20% grey and 20% white grey brown colours. The WLPK females had 40% grey white spot, 20% white grey, 20% grey plus white and 20% black with spot brown colours. However, PKWL males had 40% white, 60% cream-white. The PKWL females had 40% and 60% white grey colour. White Leghorn dominated with its colour again, they seemed to have strong gene that influence its phenotypic character. Similar dominants were noticed on the head phenotypic characteristics.

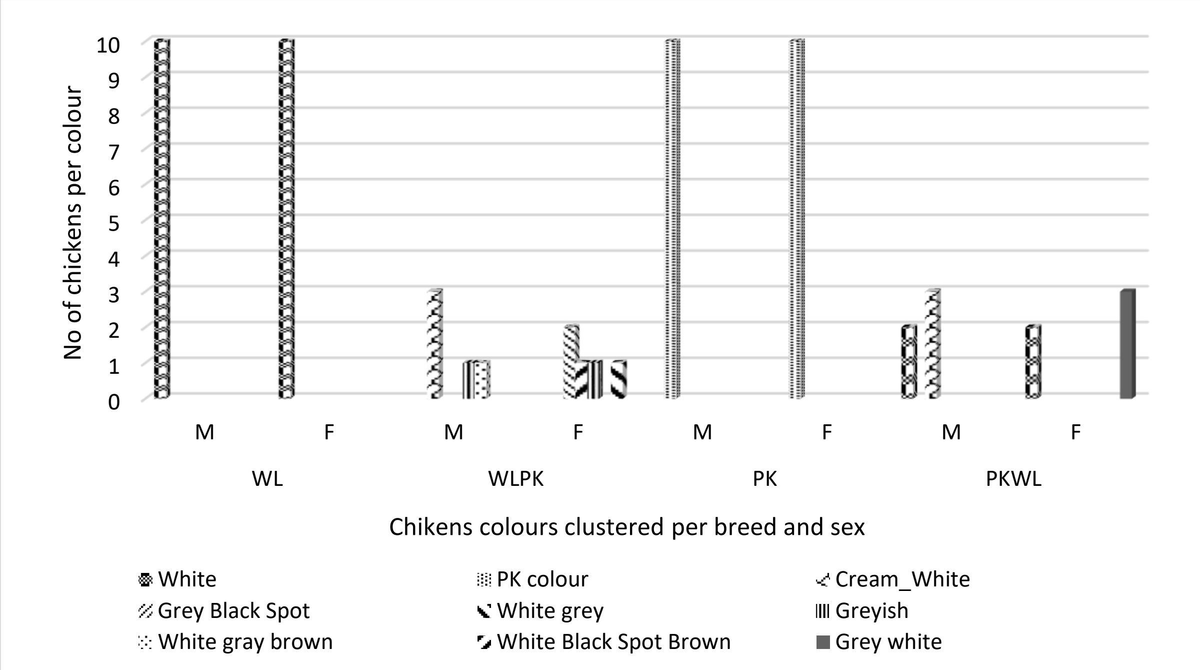


Figure 4.15: Feather colours for WL, PK and their F1 offspring from crossbreeding Change grey to grey in white grey brown

4.5.4 Feather distribution

Breeds used in the current study had two pattern of feather distribution, which is normal and naked neck. The Naked neck breed somehow dominated the distribution of colour on its crossbred offspring irrespective of the use of Naked neck sire or dam. Figure 4.16 Feather distribution of several offspring from crossbred and reciprocal.

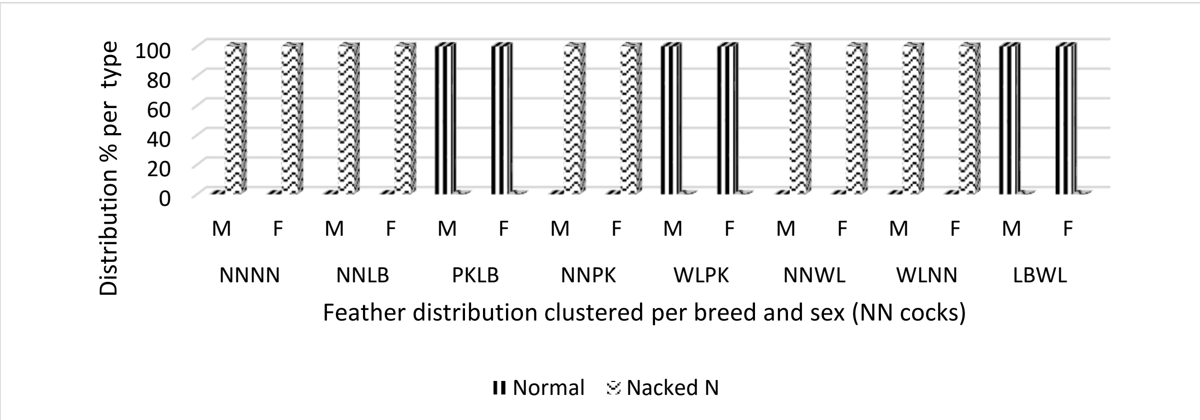


Figure 4.16: Feather distribution of F1 offspring from pure and crossbreeding

4.6 GENERAL COMBINE ABILITY, HYBRID VIGOUR AND HETEROSIS ANALYSIS ON BODY STRUCTURES

Table 4.3: presents the general combining ability (GCA) and hybrid vigour of the crossbreed body structures. The GCA on body weight for NNLB was 95 g representing 5.4% of combine ability from both sire and dam. Hybrid vigour on body weight was 4.81% higher than the parent pure breed (NN) was not significant ($p > 0.05$). The hybrid vigour for body length (-2.28 mm) and wingspan (-3.20 mm) yielded negative value where body length and wingspan of NN were longer than its crossbreed NNLB and was not significant ($p > 0.05$). However, the chest circumference corresponded to the body weight with the hybrid vigour of 7.91% compared to pure NN and was significant (p 0.045).

Table 4.3: General combine ability, hybrid vigour of the body structures for crossbreeds.

	Body weight	Body length	Wing span	Chest circum	Shank Length
LBNN - GCA	-66	-5	-15	8	-6
NNLB - GCA	95	3	-4	31	9
LBPK - GCA	68	-1	-6	48	4
PKLB - GCA	177	30	16	27	2
LBWL - GCA	100	-16	-32	4	12
WLLB - GCA	96	3	-20	-3	13
PKNN - GCA	253	-2	-23	32	4
NNPK - GCA	-113	-16	-30	28	-6
PKWL - GCA	48	-5	-22	7	12
WLPK - GCA	177	13	-21	23	5
NNWL - GCA	122	1	-33	14	8
WLNN - GCA	200	-6	-24	15	9
LBNN - HV	-3,22	1,85	-0,69	4,48	-1,46
NNLB - HV	4,81	-2,28	-3,2	7,91	4,83
LBPK - HV	12,98	0,25	2,21	17,17	8,83
PKLB - HV	0,87	7,21	-0,09	6,77	-0,87
LBWL - HV	-6,38	-7,12	-8,48	-2,22	12,33
WLLB - HV	23,26	3,77	-2,8	3,06	18,44
PKNN - HV	5,07	2,2	-5,55	10,17	6,09
NNPK - HV	2,03	-6,53	-5,21	8,63	-7,16
PKWL - HV	-15,63	-4,59	-9,11	-2,93	8,15
WLPK - HV	41,46	7,19	0,72	13,76	12,6
NNWL - HV	-5,65	-5,39	-10,69	-1,01	1,64
WLNN - HV	31,96	4,79	-1,12	11,15	17,95

The LBPK obtained improved hybrid vigour on body weight by 12.98% compared to LB parents, while PKLB had lesser hybrid vigour of 0.87% improvement compared to PK parents and was significant ($p < 0.010$). The heritability of body weight for LBWL was at 1 534 g and WLLB at 1 527, and almost similar to median with minimal difference of 7 g which was not significant ($p > 0.05$). Heritability was determined by offspring body weight less 50% mean body weight of sire and dam. The heritability was determined in all phenotypic body structures that were measured from parent and offspring. The heritability outcome for body length were significantly different ($p < 0.011$) between LB pure breed and its LBWL crossbreed.

The PK and NN crossbreed (PKNN) showed the inheritance of PK sire on body weight, body length, and chest circumference, with no significant ($p > 0.05$) compared to the reciprocal NNPK. The two crossbreeds differed significantly on the wingspan ($p < 0.05$). The hybrid vigour also revealed the evidence of inheritance of the phenotypic body structures from PK sire except the chest circumference that was equal for two breeds without significant difference ($p > 0.05$). The improvement of body weight by 200g on WLNN, which was highly significant ($p < 0.0001$) compared to the initial body weight of WL. This resulted to the hybrid vigour of 31.96 % on the body weight. The maternal body revealed the inheritance of the bigger body weight of NN females with 344.30 g by WLNN highly significant ($p < 0.0001$) to WL, with no significant ($p > 0.05$) compared to -27 by NNWL.

The wattle length for PK males recorded 31.50 mm, PK females had 22.10 mm while LB males measured 36.40 mm and females 23.90 mm. The PKLB males had wattle mean of 44.20 mm and females had 23.80 mm. The LBPK males had 49.20 mm while females recorded 16.00 mm. There was significant difference between LB and its crossbreed offspring LBPK ($p < 0.0001$) and its reciprocal PKLB at ($p < 0.0001$). The PK differed with its offspring PKLB $p < 0.0001$ and LBPK ($p < 0.0001$). There was no significant ($p > 0.05$) difference between LBPK and PKLB.

The results showed that the wattles width for White Leghorn were greater than those of Naked neck in both sexes (White Leghorn male 44.70 mm, female 45.00 mm, Naked neck male 36 mm, female 10.30 mm). There were significant differences between the two pure breeds, Naked neck and White Leghorn ($p < 0.0001$). Naked neck and White Leghorn continued to show high levels of significant difference with their offspring from pure-breeding, crossbreeding and reciprocal ($p < 0.0001$).

The NNWL males showed improvement of 39.44% on the wattles width when compared to its male parent NN and was significant ($p < 0.007$). Opposite results were obtained on NNWL females whereby there was a suppression of -47.56% compared to their female parent (White Leghorn) with no significant difference ($p > 0.05$). The heterosis of the overall mean stand at -8.89%. The WLNN females had increased wattles compared to their female parent NN and led to an overall heterosis for both sexes to 21.82% and it was not significant.

The comb length of male White Leghorn measured 102.40 mm, female 25.80 mm, compared to PK male 75.80 mm, female 29.20 mm and significant difference was observed ($p < 0.014$) between the two breeds (WL and PK). The PK revealed significant difference with its offspring (PKWL) at ($p < 0.048$) and its reciprocal offspring (WLPK) ($p < 0.007$). White Leghorn did not show any significant level with its offspring.

The comb height of White Leghorn males was longer (54.10 mm) than Lohmann Brown male 34.10 mm. The Lohmann Brown females had longer (25.50 mm) comb height compared to White Leghorn female with 12.80 mm. The pure breeds and crossbreds were subjected to further analysis to determine the level of significant difference, and the results showed non-significant difference. The comb for WL male were longer than the LB male, with opposite results on females where LB was longer than WL. WLLB F1 offspring resulted in comb height for both sexes, male -6.47% female 47.45% with overall -19.60% on combine sexes. Its counterpart LBWL had an overall increase of 55.65% on combine sexes of heterosis results.

The mean comb size of pure White Leghorn breed was compared with other three pure breeds and it differed significantly at the following levels with LB ($p < 0.005$), NN ($p < 0.009$) and PK ($p < 0.014$). The other significant difference ($p < 0.007$) was recorded between mean comb size of NN and LB. The LB mean comb size for pure breed differed significantly with the following; LBWL ($p < 0.0001$), NNLB ($p < 0.004$), NNWL ($p < 0.0001$, PKLB ($p < 0.021$,) PKWL ($p < 0.023$), WLNN ($p < 0.001$) and

WLPK ($p < 0.003$. The NN mean comb size of pure breed differed significantly with the following: LBWL ($p < 0.0001$), NNLB ($p < 0.006$), WLNN ($p < 0.001$) and WLPK ($p < 0.004$). The PK pure breed differed significantly with NNWL ($p < 0.0001$), WLNN ($p < 0.002$) and WLPK ($p < 0.007$). The WL pure breed differed significantly ($p < 0.030$) with only one crossbreed, NNWL. The two crossbreeds, LBWL and NNWL differed significantly to other crossbreeds.

The comb height mean for NN male was 33.00 mm while PK male stand at 36.20 mm. The comb height mean for NN female was 11.40 mm and for PK female was 10.90 mm. There were no significant differences between comb heights mean of NN and PK. There was no significant difference between NN and NNPK. However, the level of significant was noticed between NN and NNNN ($p < 0.045$). The PK did not show any significant differences ($p > 0.05$) with any of its offspring from pure-breed, crossbreed and reciprocal.

Table 4.4 shows the calculated heterosis percentage of the comb and wattles of the crossbred offspring. The heterosis was tested on all phenotypic characteristics of the head, NNPK male yielded 9.7% of NN male without significant difference ($p > 0.05$). The NNPK females recorded 46.79% above dam PK, while both sexes mean achieved heterosis of 18.91%. The PKNN females suppressed heterosis of -12.15% and brought the heterosis of the overall mean for both sexes to 2.10%.

Table 4.4: The percentage of heterosis from Sire and Dam on the Comb and wattles of crossbreed chickens

	Comb Length			Com height			Wattles Length			Wattles width		
Breed	Sire	Dam	Offspring	Sire	Dam	Offspring	Sire	Dam	Offspring	Sire	Dam	Offspring
LBNN	8,45	18,24	11,41	5,57	49,12	16,48	20,88	11,70	17,75	43,13	129,13	64,42
NNLB	21,34	70,82	35,27	45,45	-74,10	-6,66	50,62	10,46	33,57	43,13	129,13	64,42
LBPK	23,98	-21,23	11,11	42,52	37,61	41,33	35,16	-27,60	11,45	56,55	70,25	60,37
PKLB	18,73	35,94	23,39	-0,55	-36,47	-15,40	40,32	-0,42	22,74	24,51	87,40	41,08
NNPK	7,95	36,30	16,15	9,70	46,79	18,91	29,01	-2,26	16,33	6,11	109,92	32,22
PKNN	0,00	37,74	11,15	-12,15	47,37	2,10	40,32	38,30	39,56	13,24	129,13	39,30
NNWL	52,30	70,54	57,13	65,45	70,31	66,81	60,49	45,95	55,93	39,44	-47,56	-8,89
WLNN	-3,12	32,08	5,22	-7,58	75,44	6,87	69,32	-4,26	43,07	7,83	82,52	21,82
PKWL	12,93	63,57	25,79	58,56	67,19	60,82	63,17	8,11	45,57	34,65	-48,89	-12,05
WLPK	-1,17	20,55	3,65	3,14	50,46	11,08	49,85	-33,94	16,79	10,07	85,12	26,06
WLLB	-17,38	23,13	-8,66	-6,47	-47,45	-19,60	26,25	-37,24	0,00	-32,89	38,58	-17,07
LBWL	15,26	34,11	20,16	54,25	59,37	55,65	42,31	27,03	37,89	69,97	-39,56	5,37

The multiple comparisons of comb height across all the chicken breeds were used in the current study. Naked neck significantly differed appeared to be the breed that had most (11) significant differences than other breeds on comparisons of comb height. Most of differences came from the crossbreeding of White Leghorn with other breeds and Potchefstroom Koekoek offspring from crossbreeding.

White Leghorn showed high levels of significant difference on the comb sizes of 12 genotypes ranging from ($p < 0.0001$ to $p < 0.031$). Naked neck was the second breed with most (10) significant difference than other breeds on wattle length. White Leghorn wattles size differed significantly with 14 genotypes. The non-significant difference observed on LBWL. The phenotypic characteristics of White Leghorn differ to other breeds and had impacts of improvement on its offspring compared to other breeds. The suppression of phenotypic head characteristics was also noticed on offspring that come from crossbreeding of WL and other breeds.

4.7 EGG PRODUCTION PERCENTAGE AND GCA FOR F1 PURE BREEDS, CROSSBREED AND RECIPROCAL

Figure 4.17 presents the egg production mean per hen per breed in sequence of small to largest producer. The PKNN was the lowest producer followed by its reciprocal NNPK. The third lowest producer was pure breed, Naked neck. Naked neck produced 61% of what LB had produced. The NNLB produced 73% while LBNN produced 62% of LB production. The difference between LBNN and NN was only 1%. The NNLB hens showed increased production of 20% compared to NN hens. The combine ability for NNLB hens was at -17.05% while maternal effects also recorded negative at -27.00%. The LBNN had negative and positive results with GCA of -43.59% and maternal effects of 1.09%. There was a slight improvement on the maternal effects of NN by LB cocks and LBNN was 1.09% above its NN female parent and it was not significant ($p > 0.05$).

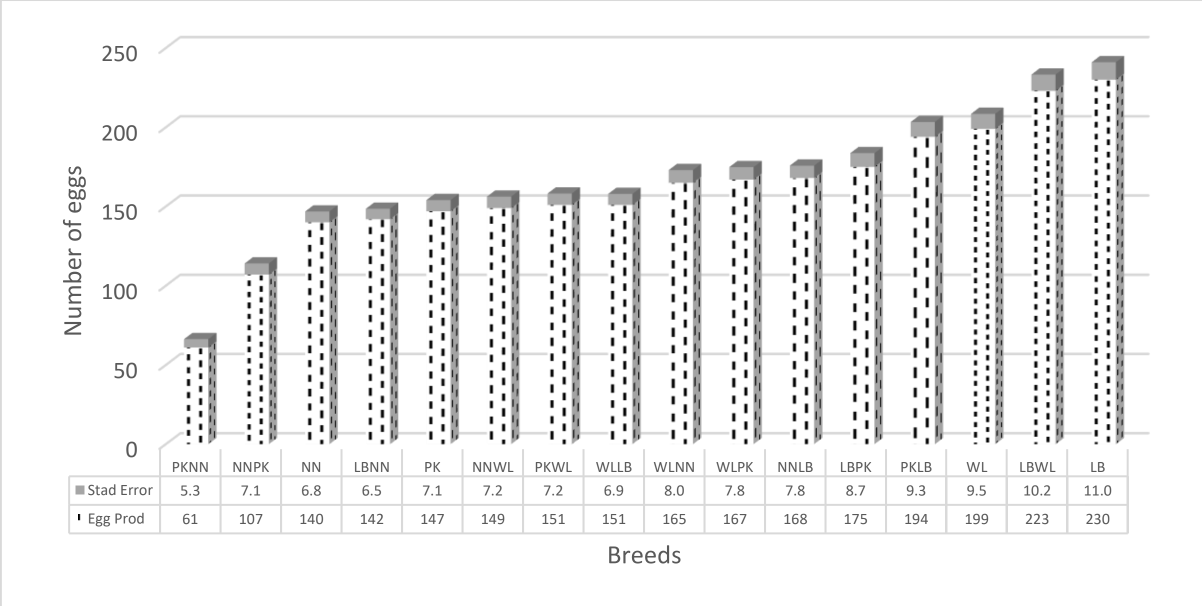


Figure 4.17: Egg production means for all breeds

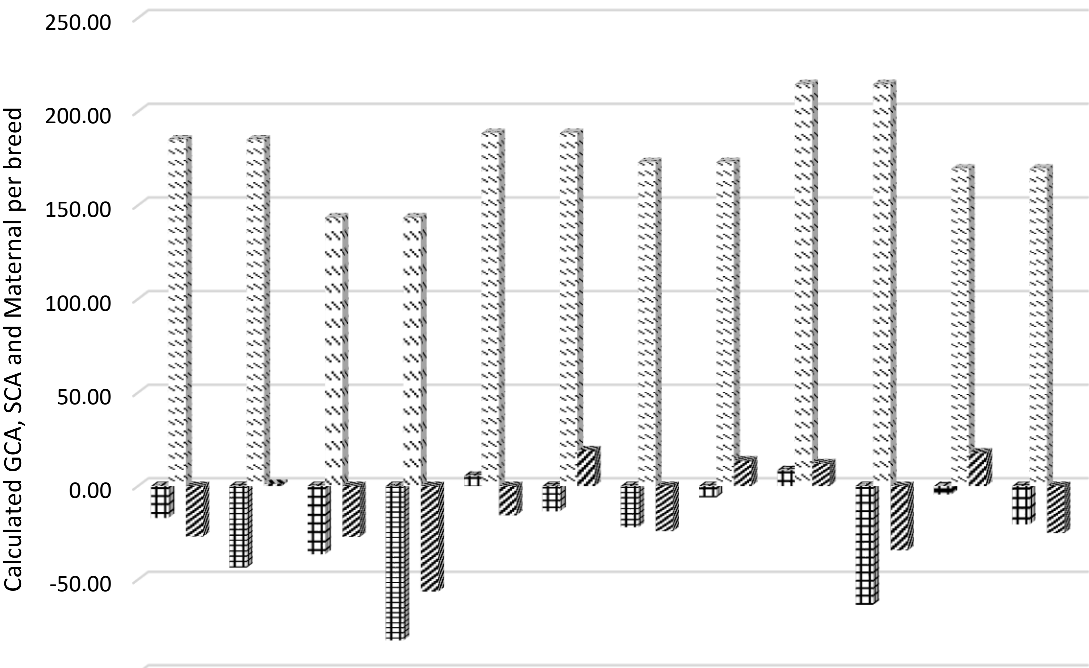
The mean egg production per hen of PK was 147 eggs and NN produced 140 eggs at the age of 40 weeks. The NNPK females produced up to 73% of PK total production when PKNN produced up to 42% of eggs. The GCA for NNPK was at -36.50 while PKNN worsen to -82.50. The maternal effects also recorded negative when NNPK –27.21% and PKNN – 56.43%.

The egg production for these two breeds were compared whereby PK produced 147 eggs, which was 64% of what LB produced 230 eggs at the age of 44 weeks. The LBPK hens produced 175 eggs which is 27 eggs more compared to their female PK parent at the same period. The PKLB females produced 194 eggs and showed suppression of production by 26% compared to the production of their female parent LB. The GCA for LBPK -13.50% with the improvement of maternal effects at 19.05%. The GCA for PKLB was at 5.50 while the maternal effects experienced the suppression of -15.65%.

The results revealed that each White Leghorn hen laid 52 eggs more than Potchefstroom Koekoek in the same period under the same environmental conditions. The GCA for WLPK was -6.00 with the improvement on maternal effects by 13.61%. The GCA for reciprocal PKWL was at -22.00 with further suppression of maternal effects by -24.12%.

The commercial breed LB produced 31 eggs more than White Leghorn under the same period of production. The introduction of LB cocks on LB hens led to the improvement of egg production whereby LBWL hens produced average of 24 eggs more than WL parent. The GCA revealed that WLLB -63.50 with further suppression of maternal effects at -34.35%. Indeed, LB cocks improved the ability of WL hens. The GCA for LBWL recorded 8.50 with significant improvement of maternal ability by 12.06%. The indigenous chicken breed, Naked neck hens produced 70% of what White Leghorn hens produced. The WLNN hens achieved the GCA of -4.50, with maternal ability of 17.86%.

The general combining ability, special combining ability and maternal effects was calculated on growth production traits and egg production. Figure 4.18 presents the general combining ability, special combining ability and maternal effects for egg production of crossbred offspring against their reciprocal.



	NNLB	LBNN	NNPK	PKNN	PKLB	LBPK	PKWL	WLPK	LBWL	WLLB	WLNN	NNWL
GCA	-17.05	-43.59	-36.50	-82.50	5.50	-13.50	-22.00	-6.00	8.50	-63.50	-4.50	-20.50
SCA	185.13	185.13	143.50	143.50	188.50	188.50	173.00	173.00	214.50	214.50	169.50	169.50
Maternal	-27.00	1.09	-27.21	-56.43	-15.65	19.05	-24.12	13.61	12.06	-34.35	17.86	-25.13

GCA, SCA and maternal per breed

Figure 4.18: GCA, SCA and maternal of crossbreeds and their reciprocal

4.7.1 Graded eggs per genotype

Table 4.5 shows the category and number of dozens graded eggs from offspring of LB, NN pure breeding and crossbreeds. The results showed that on average one hen LBLB produced 19.19 dozens when NNNN produce 11.67 dozens at the age of 44 weeks with significant of ($p < 0.0001$). The LBNN did not differ significantly ($p > 0.05$) with NNNN on Jumbo and extra-large but differed ($p < 0.039$) on large category. The NNLB produced 14 dozens but did not differ significantly ($p < 0.05$) with LBNN.

Table 4.5: Category and number of dozens graded from offspring of LB, NN pure breeding and crossbreeds.

	Jumbo		X-Large		Large		Medium		Small		Cracks	
Breed	**Mean**	**Std. Deviation**	**Mean**	**Std. Deviation**	**Mean**	**Std. Deviation**	**Mean**	**Std. Deviation**	**Mean**	**Std. Deviation**	**Mean**	**Std. Deviation**
LBXLB	2,517	5,748	35,966	21,327	53,828	50,860	25,897	66,091	6,310	23,187	2,1034	4,1434
LBXNN	0,793	1,677	11,690	10,142	65,000	167,648	27,759	38,331	8,172	26,913	3,4483	5,2207
LBXPK	0,414	0,733	24,207	36,763	35,241	24,690	32,138	47,243	4,759	15,357	4,6897	6,5906
LBXWL	0,241	0,577	29,621	23,286	74,621	32,132	43,586	79,209	10,103	35,993	2,7931	4,6551
NNXLB	0,571	1,289	12,750	12,045	46,786	36,225	35,000	54,657	8,214	31,481	3,2069	5,9304
NNXNN	0,321	0,612	6,571	6,449	37,536	27,673	63,250	150,755	20,857	87,552	2,0714	3,0053
NNXPK	0,250	0,585	5,107	3,975	18,214	28,190	30,000	33,414	9,536	26,873	2,0357	2,3011
NNXWL	0,464	0,637	12,071	8,210	32,464	29,836	27,107	34,173	5,750	19,705	2,6786	3,4860
PKXLB	0,571	1,230	8,929	6,140	51,500	33,037	39,714	42,317	12,250	39,362	2,2143	3,0955
PKXNN	0,000	0,000	2,286	2,623	11,286	12,250	16,643	16,846	6,214	17,167	2,2857	2,9547
PKXPK	0,036	0,189	2,250	3,931	22,929	15,757	44,357	34,605	16,000	38,715	1,9643	2,6315
PKXWL	0,250	0,518	11,607	7,613	34,179	21,269	33,107	41,371	7,750	27,670	3,0357	4,7725
WLXLB	1,103	1,448	10,966	7,023	41,483	24,635	39,414	55,087	10,310	33,241	3,1071	4,1306
WLXNN	0,207	0,491	4,276	5,284	27,759	27,416	45,345	50,654	19,000	59,437	6,1034	8,9855
WLXPK	0,138	0,441	12,034	12,749	38,103	26,342	27,759	32,867	6,793	28,229	2,2414	3,4605
WLXWL	0,103	0,557	6,517	11,792	54,517	41,327	49,345	61,004	12,828	45,763	4,4138	6,5166

Table 4.6 shows the estimated return per hen in different egg grades in South African currency (rand). The two breed LB and NN produced most of their eggs in two categories, LB produced large 8 dozens while NN produced 3 dozens and was not significant ($p > 0.05$). The production of extra-large category between these two breeds was led by LB with 5 dozens which was highly significant ($p < 0.0001$) to production on NN with 0.5 dozen.

Table 4.6: Sales of graded eggs from all genotypes

	Jumbo	**X-Large**	**Large**	**Medium**	**Small**	**Cracks**	**Total return**
LBLB	R 10.68	R 141.69	R 195.75	R 86.33	R 19.12	-R 7.65	**R 453.57**
LBPK	R 1.67	R 90.53	R 121.66	R 101.70	R 13.69	-R 16.19	**R 329.24**
LBNN	R 2.24	R 30.68	R 157.45	R 61.64	R 16.50	-R 8.35	**R 268.51**
LBWL	R 0,78	R 88,82	R 206,54	R 110,59	R 23,30	-R 7,73	**R 430,02**
PKPK	R 0.14	R 8.11	R 76.32	R 135.35	R 44.38	-R 10.10	**R 264.30**
PKLB	R 2.25	R 32.61	R 173.64	R 122.75	R 34.42	-R 7.71	**R 365.67**
PKNN	R -	R 7.82	R 35.63	R 48.17	R 16.35	-R 6.20	**R 107.97**
PKWL	R 0.98	R 42.22	R 114.75	R 101.89	R 21.68	-R 10.43	**R 281.52**
NNNN	R 0.80	R 15.27	R 80.50	R 124.35	R 37.28	-R 4.37	**R 258.20**
NNLB	R 2.13	R 44.06	R 149.23	R 102.33	R 21.83	-R 6.61	**R 319.58**
NNPK	R 0.95	R 18.03	R 59.37	R 89.64	R 25.90	-R 8.73	**R 193.89**
NNWL	R 1.84	R 44.44	R 110.32	R 84.44	R 16.28	-R 7.52	**R 257.31**
WLWL	R 0,38	R 22,36	R 172,67	R 143,26	R 33,86	-R 7,64	**R 372,53**
WLLB	R 3,56	R 32,84	R 114,67	R 99,87	R 23,75	-R 16,87	**R 274,69**
WLNN	R 0.81	R 15.48	R 92.76	R 138.90	R 52.91	-R 7.49	**R 300.85**
WLPK	R 0.60	R 48.90	R 142.90	R 95.43	R 21.23	-R 16.55	**R 309.07**

The LB and its production show high significant difference ($p < 0.0001$) to PK, LBPK and PKLB on jumbo category. The commercial pure-breed offspring LBLB, led with a total number of 19 dozens compared to dual-purpose breed (Potchefstroom Koekoek) that produced 12 dozens which were even lower than other PK offspring from crossbreeding. The PKLB showed the inheritance of good maternal ability from their female parent LB hen by producing an average of 16 dozens and was significant ($p < 0.034$) was achieved only on large category and there was no significant to other categories. The reciprocal, LBPK showed some improvement by producing 14 dozen with significant of ($p < 0.0001$) to PK and ($p < 0.002$) to LB on large egg category. The purebred PK offspring recorded an average of R264.30, which was 58% of what LB purebred made on egg sales. The PKLB had a return of R365.67 while LBPK made R329.24 from its sales and was not significant ($p > 0.05$).

The WL produced dozens between large 7.19 and medium 6.51. Similar trend recorded on lower producer WLLB whereby a hen produced an average of 4.54 dozens of medium and 4.78 dozen of large eggs with no difference ($p > 0.05$). There was difference of one dozen between the pure breed offspring where, NN produced 11 dozens and PK produced 12 dozens resulting in no significant difference ($p > 0.05$). The overall income was close with difference of R6.10. The PKNN was the lowest producer and its return was low recording just R107.97 but the egg production did not differ significantly ($p > 0.05$) with PK, NN in all category of graded eggs.

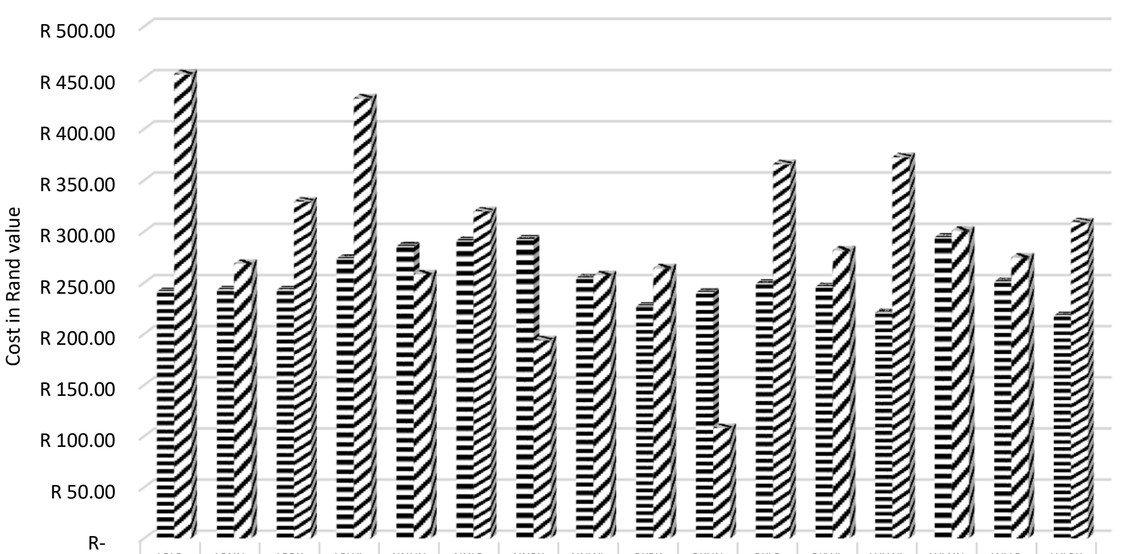
The NN and NNWL produced 11 dozens of eggs, WLNN 13.76 dozens and WL 16.59 dozens at the age of 44 weeks. There was no significant difference ($p > 0.05$) between WL, WLNN, NNWL and NNNN in graded egg categories, except least significant difference ($p < 0.043$) between WL and WLNN. The return between NN and NNWL was less than R1, at an average of R257.31 and R258.20 and it resulted in similarity. The WL produced an average of 16 dozens, which is higher than PK, (12 dozens) with no significant difference ($p > 0.05$). The PK showed significant difference to its offspring as follow, PKWL ($p < 0.014$), WLPK ($p < 0.010$).

4.7.2 Multi-comparison of graded eggs mean between breeds

There was significant difference between LBLB and six breeds on jumbo eggs means, LBWL ($p < 0.043$), PKNN ($p < 0.010$), PKPK ($p < 0.012$), WLNN ($p < 0.034$), WLPK ($p < 0.022$) and WLWL ($p < 0.017$). Fewer breeds that laid few jumbo eggs on this category influenced the level of significant on jumbo size. The LBLB differed significantly with NNNN, PKPK, PKLB, WLLB, WLNN and WLWL ($p < 0.0001$). The

LBLB continued to differ significantly with LBNN, NNWL, PKWL, WLNN ($p < 0.001$) and NNLB at ($p < 0.002$) on extra-large egg size category. The LBWL also differed significantly with PKNN, PKPK, WLNN, at ($p < 0.000$), NNNN, WLWL at ($p < 0.002$), and PKLB at ($p < 0.020$) on extra-large category. The LBPK differed significantly to three breeds only, PKNN, PKPK ($p < 0.007$), WLNN ($p < 0.031$) on extra-large category.

Figure 4.19 illustrates the mean cost and return per hen per breed. Mean cost cover the rearing and production feed cost only. The crossbreed between WLPK recorded the lowest feed cost at R217.68 follow by WL at R220.76 and PK and R226.91 and it was not significant ($p > 0.05$). The three breeds recorded the highest cost on feeds are WLNN with R294.33, NNLB with R291.18 and NN with R285.62 but showed similarity ($p > 0.05$).



	LBLB	LBNN	LBPK	LBWL	NNNN	NNLB	NNPK	NNWL	PKPK	PKNN	PKLB	PKWL	WLWL	WLNN	WLLB	WLPK
Feed cost	R 241.19	R 242.92	R 242.87	R 273.52	R 285.62	R 291.18	R 292.62	R 254.68	R 226.91	R 240.34	R 249.30	R 246.15	R 220.76	R 294.33	R 250.95	R 217.68
Returns	R 453.57	R 268.51	R 329.24	R 430.02	R 258.20	R 319.58	R 193.89	R 257.31	R 264.30	R 107.97	R 365.67	R 281.52	R 372.53	R 300.85	R 274.69	R 309.07

Figure 4.19: Feed cost and return on egg sale per breed

4.8 EGG PARAMETERS

4.8.1 Eggshell colour for F1 offspring genotype

Four different breeds used in the current study had three different colours of eggshell. Lohmann Brown laid brown eggs, White Leghorn laid white eggs while Potchefstroom Koekoek and Naked neck laid medium brown eggshell eggs. The eggshell colour presented from pure breed and crossbreed to enable to determine if there was some element of genetic transformation. Picture 4.5 shows the eggshell colour for Naked neck purebred, crossbreed and reciprocal offspring. The eggshell colour for pure NN and NNPK had similar distribution medium brown colours.

Naked neck and crossbreeds

Naked neck and reciprocals

Picture 4.5: Eggshell colour for Naked neck purebred, crossbreed and reciprocal offspring

Eggshell for PKWL offspring was whiter than those for PK and other two PK crossbreeds. White Leghorn continued to show its dominance on eggshell of its female parent offspring. Picture 4.6 shows the eggshell colour for White Leghorn, purebred, crossbred and reciprocal offspring. The reciprocal WLPK had few white eggshell compared to PKWL. The PKLB and LBPK had similar eggshell colours. Some minor variation was noticed between PKNN and NNPK.

Pure PK and PK crossbreeds Pure PK and PK reciprocals

Picture 4.6: Eggshell colour for Potchefstroom Koekoek purebred, crossbreed and reciprocal offspring

WLLB reciprocal had whiter eggshell in comparison to those of LBWL crossbreed. The LBPK and LBNN laid eggs with white eggshell colour while PKLB had browner eggshell colour than NNLB. Further observation can be seen on Picture 4.7, which illustrates the eggshell colour for LB purebred, crossbred and reciprocal offspring.

Pure LB and LB crossbreeds Pure LB and LB reciprocals

Picture 4.7: Eggshell colour for Lohmann Brown purebred, crossbred and reciprocal offspring

White Leghorn chickens laid eggs with white eggshell colour. The current study revealed some level of White Leghorn capability to dominate all breeds that were cross with it. Picture 4.7 shows the eggshell colour for White Leghorn purebred, crossbred and reciprocal offspring. Surprisingly, WLPK had more brown eggs than

WLLB and LBWL. The WLLB had lighter shade of eggshell than LBWL. The WLNN and NNWL had lighter shade of eggs than PKWL, LBWL, WLLB and WLPK. The colours of eggshells were correlated to phenotypic characteristic results on the interpretation of genetic results.

Pure WL and WL crossbreeds

Pure WL and reciprocals

Picture 4.8: Eggshell colour for White Leghorn purebred, crossbreed and reciprocal offspring

4.8.2 Exterior egg quality results

Table 4.7 shows the mean weight and circumference of eggs from sixteen genotypes. The variable means for NNWL were as follows; egg weight 62.1 g, length circumference 160 mm and width circumference 137.54 mm. The egg height 58.788 mm and egg width 13.229 mm were discovered as greatest measure under NNWL. The multivariate analysis for length and width circumference reveals high significant level ($p < 0.001$) between the breeds. The LBNN held the second position with the heaviest egg weight of 61.9 g, length circumference 160 mm, width circumference 137.58 mm and egg height 57.806 mm. The NNLB held sixth positions on the overall egg production but, managed to find itself on third position regarding the weight mean measured during exterior egg quality. There was no significant ($p > 0.05$) between NNLB and LBNN on egg production. The NN purebred offspring held the second last position after PK purebred offspring on the overall means of exterior egg quality variables. The multivariate analysis on egg weight and circumference show significant ($p < 0.05$) among the breeds.

Table 4.7: Illustrate the mean weights and circumference of eggs from sixteen genotypes.

Breed	Egg weight (g)	Tape length circum. (mm)	Tape Width circum. (mm)	Vanier Calliper Height (mm)	Vanier Calliper Width (mm)
LBLB	58.0	156.9	135.250	56.441	13.525
LBNN	61.9	175.6	137.583	57.806	13.758
LBPK	58.8	172.8	135.417	56.418	13.542
LBWL	54.7	173.0	132.583	57.402	13.258
NNLB	59.4	174.7	135.250	58.240	13.525
NNNN	54.8	169.0	132.333	55.968	13.233
NNPK	55.5	171.8	130.292	58.260	13.029
NNWL	62.1	175.5	137.542	58.788	13.754
PKLB	57.4	173.3	132.292	58.250	13.229
PKNN	57.1	172.1	132.458	57.439	13.246
PKPK	53.3	169.9	130.042	56.853	13.004
PKWL	57.9	173.4	134.600	58.044	13.460
WLLB	58.3	174.8	134.250	58.391	13.425
WLNN	57.8	172.4	134.408	57.094	13.441
WLPK	58.6	173.9	135.375	57.693	13.538
WLWL	58.6	174.5	134.292	58.056	13.429

Table 4.8 shows the eggshell weight, shell thickness and yolk weight for all sixteen genotypes used in phase 2 of research project. The NNWL continued to lead with the mean of 8.292 g for eggshell weight and 21.063 g for yolk weight. Its shell thickness recorded the 5th position across all sixteen genotype. The WLLB held the second position while LBLB was in third position regarding eggshell mean weight. The yolk weight and eggshell thickness did not differ in terms of colour percentage. The second-best egg producer LBWL found itself on the 2nd position after LBPK on comparison of eggshell thickness. The effect of breed intercept on egg weight and

effect on breed and egg weight tested with multivariate and the outcome shows high significant difference ($p < 0.0001$) in all variate.

Table 4.8: The mean for eggshell weight (g), shell thickness and yolk weight of sixteen genotype.

	Shell weight		**Shell thickness**		**Yolk weight**	
	Mean	**Std. error**	**Mean**	**Std. error**	**Mean**	**Std. error**
LBLB	7.738	0.0034	0.424	0.0002	18.119	0.0063
LBNN	7.611	0.0033	0.408	0.0002	19.111	0.0060
LBPK	7.500	0.0032	0.456	0.0002	17.444	0.0059
LBWL	7.024	0.0036	0.440	0.0002	17.298	0.0065
NNLB	7.317	0.0036	0.403	0.0002	19.483	0.0066
NNNN	6.583	0.0034	0.350	0.0002	18.500	0.0062
NNPK	7.063	00033	0.401	0.0002	17.729	0.0061
NNWL	8.292	0.,0033	0.402	0.0002	21.063	0.0061
PKLB	7.056	0.0032	0.357	0.0002	20.000	0.0059
PKNN	7.133	0.0032	0.381	0.0002	19.300	0.0059
PKPK	6.643	0.0035	0.365	0.0002	19.357	0.0063
PKWL	7.024	0.0034	0.368	0.0002	19.214	0.0063
WLLB	8.130	0.0033	0.378	0.0002	19.778	0.0060
WLNN	7.463	0.0033	0.381	0.0002	20.926	0.0060
WLPK	7.063	0.0033	0.384	0.0002	20.083	0.0061
WLWL	7.542	0.0033	0.382	0.0002	19.750	0.0061

The mean weight for albumen ranged from 27.33 g to 35.33 g among sixteen genotypes. These weights were strongly relating to the overall weight of the egg. Table 4.9 shows the weight for egg materials and weight distribution percentage. Appendix J presents the multiple comparisons of egg weight difference between the chicken breeds tested by LSD post hoc at sensitivity of 95%. The variation of egg weights led to the high significant difference among breeds. The PKPK laid eggs with the smallest weight and they were significantly different to egg weight of 12 other breeds. The PKPK was significantly different from other breeds at the following levels; LBNN and NNWL ($p < 0.0001$), NNLB ($p < 0.001$), LBPK ($p < 0.003$), WLPK, WLWL ($p < 0.004$), WLLB ($p < 0.006$), LBLB ($p < 0.010$), PKWL ($p < 0.011$), WLNN ($p < 0.002$), PKLB ($p < 0.023$) and PKNN ($p < 0.036$).

Appendix K present the multi-comparison of egg length circumference between sixteen genotypes by LSD post hoc at ($p < 0.05$). The NNNN was significant different than most of the breeds at the following levels , LBNN, WLNN ($p < 0.001$), LBWL ($p < 0.042$), PKLB ($p < 0.030$), PKWL ($p < 0.024$), WLLB ($p < 0.003$), WLPK ($p < 0.012$) and WLWL ($p < 0.005$). The multi-comparisons of egg yolk weight means between sixteen genotypes presented in appendix L for further interpretation. Five breeds had egg length circumference that were significantly different than other breeds. The NNWL and WLNN recorded significantly different egg length circumference than the other 13 breeds, followed by LBWL and NNPK and LBPK.

Table 4.9: Egg weights (g) distribution percentage per category

	Egg weight		Shell weight		Yolk weight		Albumen	Egg weight distribution %		
	Mean	**Std. Error**	**Mean**	**Std. Error**	**Mean**	**Std. Error**	**Est. Mean**	**Shell (%)**	**York (%)**	**Albumen (%)**
LBNN	58.00	2.37	7.67	0.78	18.00	0.74	32.33	13.22	31.03	55.75
LBPK	61.92	3.78	7.33	0.89	19.25	0.75	35.33	11.84	31.09	57.07
LBWL	58.75	4.22	6.83	0.83	17.42	1.51	34.50	11.63	29.65	58.72
NNLB	54.67	2.84	7.33	0.65	17.17	0.83	30.17	13.41	31.40	55.18
NNNN	59.42	3.90	6.75	0.62	19.00	1.21	33.67	11.36	31.98	56.66
NNPK	54.75	4.20	7.08	0.51	18.50	1.24	29.17	12.94	33.79	53.27
NNWL	55.50	4.66	8.25	1.22	17.58	1.44	29.67	14.86	31.68	53.45
PKLB	62.08	6.96	6.92	0.90	20.92	1.16	34.25	11.14	33.69	55.17
PKNN	57.42	5.32	7.17	0.72	19.67	2.10	30.58	12.48	34.25	53.27
PKPK	57.08	4.23	6.42	1.00	19.42	1.08	31.25	11.24	34.01	54.74
PKWL	53.25	4.22	7.00	0.60	18.92	1.38	27.33	13.15	35.52	51.33
WLLB	57.92	3.82	7.92	1.00	19.17	1.75	30.83	13.67	33.09	53.24
WLNN	58.25	6.73	7.50	0.67	19.83	1.64	30.92	12.88	34.05	53.08
WLPK	57.83	3.46	7.17	0.83	20.92	1.44	29.75	12.39	36.17	51.44
WLWL	58.58	3.50	7.42	0.67	20.17	1.53	31.00	12.66	34.42	52.92

4.8.3 Interior egg quality results for F1 offspring eggs

It was important for the current study to determine the yolk colour of F1 offspring crossbreed eggs. The colours were determine using the DSM YolkFan TM on all eggs. The colours are coded in numbers, the lightest yellow as code 1 and darkest yellow as code16. Figure 4.20 shows egg yolk colour for NN and LB purebred and offspring. The results revealed that about 58% of eggs measured from LB were in colour code 5; 25% were in code 6 and 17% were in code 7. The indigenous chicken (NN) had the darker yolk colour than commercial breeds. Only 8% of measured eggs scored under code 7, which was the darkest code for LB with fewer eggs than other codes. Majority of NN eggs had darker colour than LB and did not reach 33% for code 8, 42% for code 9 and 17% for code 10. The offspring come with the interesting results whereby both LBNN and NNLB scored 67% for code 6.

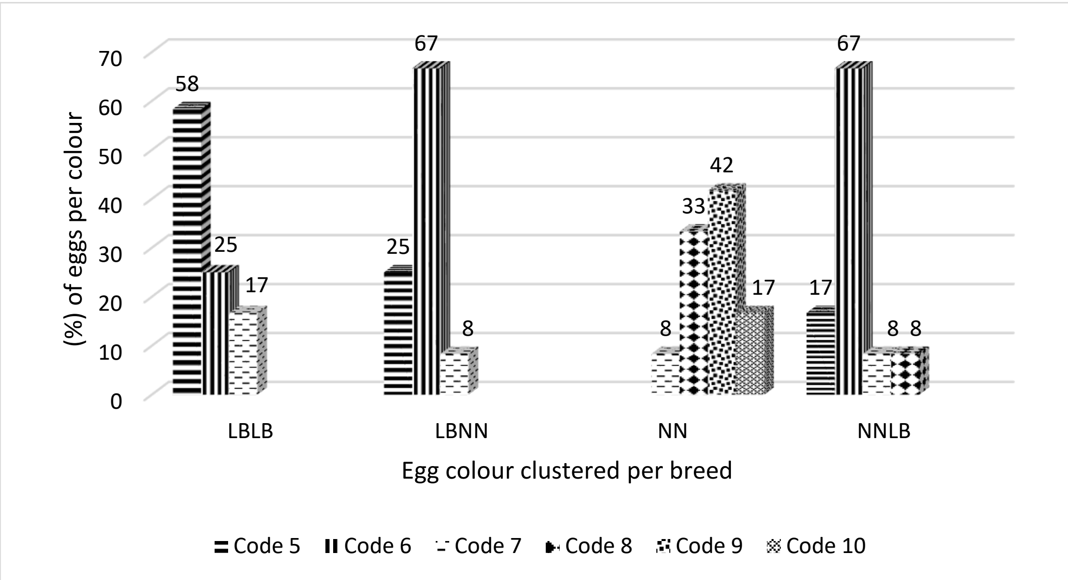


Figure 4.20: Egg yolk colour for NN and LB purebred and offspring

Egg yolk colour for LB and PK purebred and offspring are in Figure 4.21. Potchefstroom Koekoek had fewer egg yolk colour variation that were slightly darker than LBLB. The LBLB scored 17% for code 7, which was the darkest colour while PK score 42% for the same code and 17% for code 8, which was its darkest colour. The LBPK showed the balance general combine ability from both parents with 50%

for code 6 and 42% for code 7. The shift of colours was observed on PKLB where 33% of egg yolk colour shifting to code 9 which was not recorded from both parents.

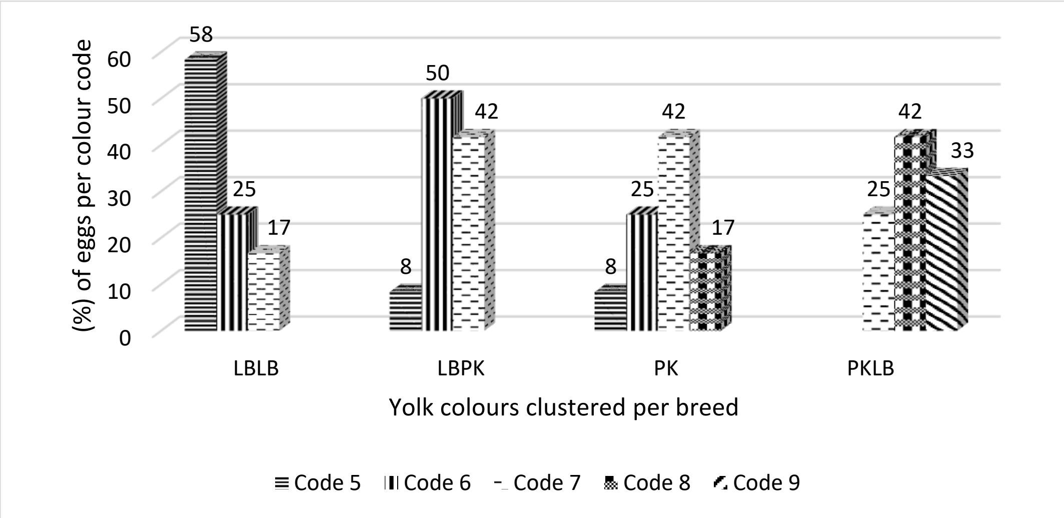


Figure 4.21: Egg yolk colour for LB and PK purebred and offspring

Naked neck had slightly darker egg yolk colour than Potchefstroom Koekoek. Figure 4.22 shows the egg yolk colour for NN and PK purebred and offspring. The NNPK produced the yolk colour codes as follow, 8% for code 6, 50% for code 7, 33% for code 8 and 8% for code 9. For PKNN 83% of eggs scored under code 8 and 17% was for code 7.

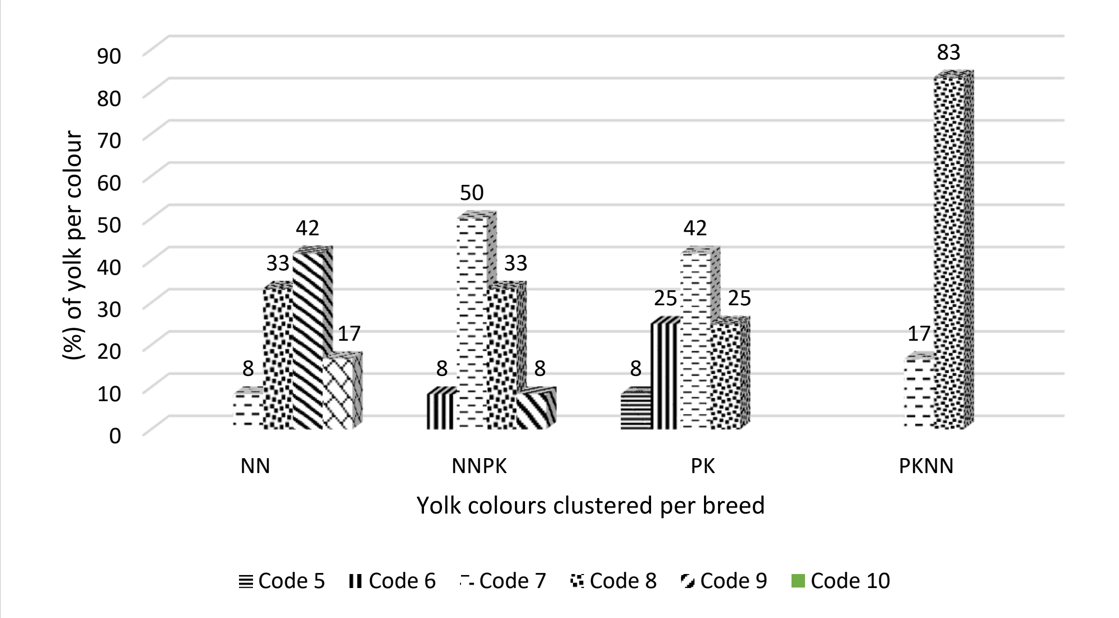


Figure 4.22: Egg yolk colour for NN and PK purebred and offspring

White Leghorn had lighter egg yolk colours than Naked neck. Figure 4.23 shows the egg yolk colour for NN and WL purebred and offspring. The results indicated that 92% of White Leghorn egg yolk colours were lighter than yolk colours of Naked neck. The 92% of yolk colours recorded for NN was not found in any of its offspring between NN and WL.

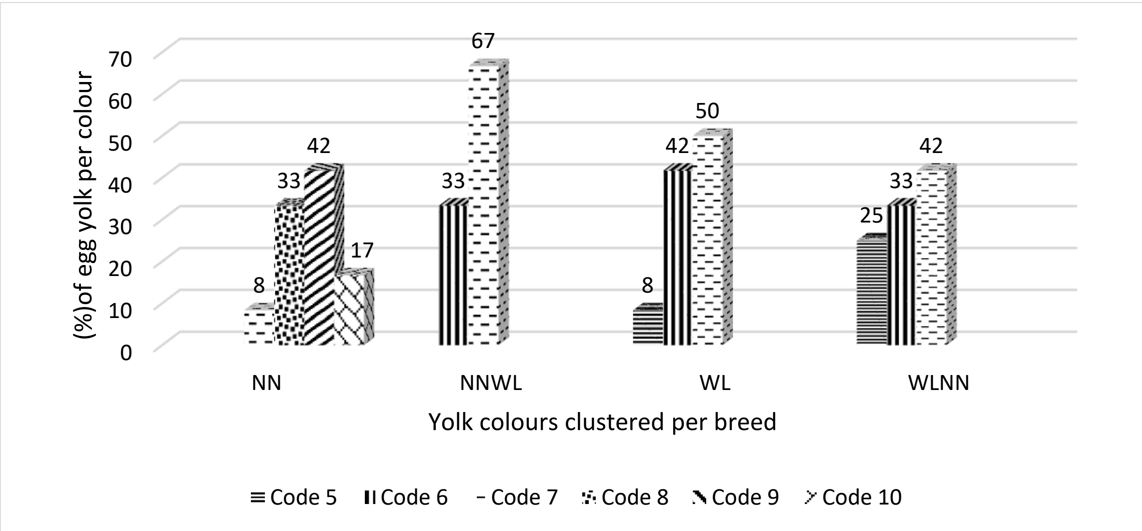


Figure 4.23: Egg yolk colour for NN and WL purebred and offspring

The results in Figure 4.24 shows that 25% of PK egg yolk colours were darker than colours recorded on WL purebred offspring. Both PK and WL scored 8% for colour code 5. Surprisingly, there was a shift of egg colour to the lighter colour code 5 for both PKWL with 33% and WLPK with 50%.

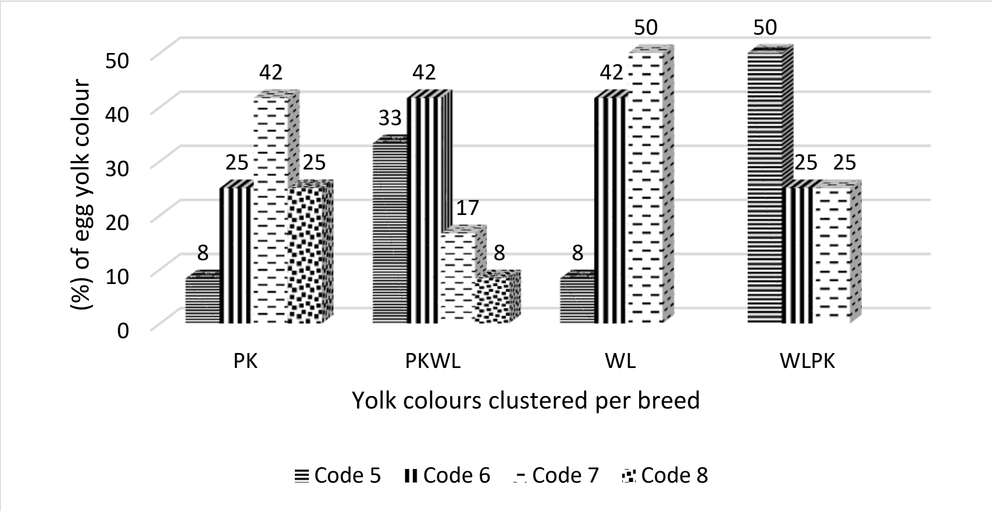


Figure 4.24: Egg yolk colour for PK and WL purebred and offspring

White Leghorn and Lohmann Brown both produced eggs that scored under the same three codes 5, 6 and 7. Figure 4.25 reveals that LB had produced 50% lighter eggs than NN under code 5. Another slight shift to darker colours was evident on NNLB with 17% and LBNN with 42% for colour code 8. The WLLB recorded 75% of eggs for code 7.

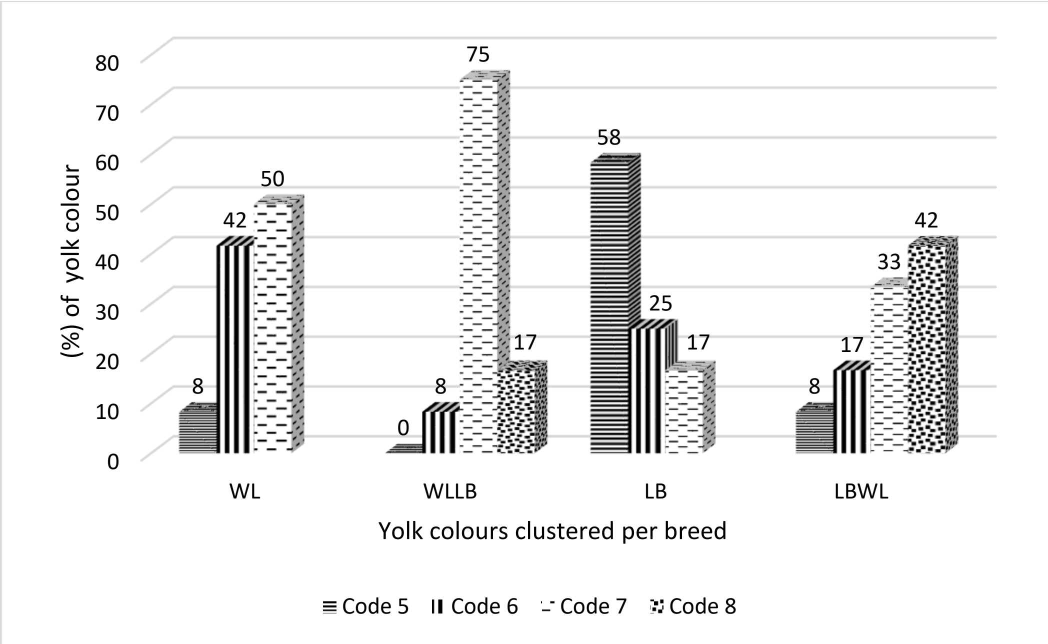


Figure 4.25: Egg yolk colour for NN and LB purebred and offspring

Table 4.10 shows the yolk and albumen height mean per breed. The White Leghorn chicken had the lowest yolk height mean at 15.650 mm, while WLPK had the second lowest height at 15.845 mm. The highest yolk was observed on NNPK measuring 18.625 mm and NN had second highest at 18.548 mm. The LB measured the highest albumen height next to yolk at 6.078 mm, followed by LBNN at 5.736 mm, WLLB at 5.413 mm and WLNN at 5.376 mm. The yolk colour was clustered per breed on the combine of all breeds due to lots of variation on colour codes per breed. The yolk height and albumen height revealed high significant level ($p < 0.0001$) among the breeds.

Table 4.10: The egg yolk and albumen height means with standard error per breed

	Yolk height		Albumen height-yolk		Albumen height	
	Mean mm	**Std. Error**	**Mean mm**	**Std. Error**	**Mean mm**	**Std. Error**
LBLB	17.390	0.323	6.078	0.158	4659	0.148
LBNN	18.343	0.323	5.736	0.158	4.393	0.148
LBPK	17.347	0.323	5.678	0.158	4.482	0.148
LBWL	17.736	0.323	5.652	0.158	4.202	0.148
NNLB	18.296	0.323	5.540	0.,158	4.992	0.148
NNNN	18.548	0.323	5.574	0.158	5.297	0.148
NNPK	18.625	0.323	5.645	0.158	4.794	0.148
NNWL	18.385	0.323	5.584	0.158	5.330	0.148
PKLB	17.401	0.323	5.318	0.158	5.207	0.148
PKNN	17.657	0.323	5.306	0.158	4.608	0.148
PKPK	17.022	0.323	5.349	0.158	5.349	0.148
PKWL	17.360	0.323	5.443	0.158	5.248	0.148
WLLB	17.562	0.323	5.413	0.158	5.413	0.148
WLNN	16.611	0.323	5.376	0.158	5.376	0.148
WLPK	15.845	0.323	5.336	0.158	5.154	0.148
WLWL	15.650	0.323	5.420	0.158	5.147	0.148

Appendix M presents the multiple comparison of egg yolk height between the chicken breeds compared by LSD post hoc test. The White Leghorn had the lowest yolk height and it differ significantly ($p < 0.0001$) to 14 breeds followed by WLPK that was highly significant to the other 13 breeds. The NNPK scored the highest yolk mean height and it was significant than ten other breeds.

CHAPTER 5

5 DISCUSION AND CONCLUSION

5.1 CROSSBREEDING OF EXOTIC, COMMERCIAL, AND LOCAL BREEDS

The crossbreeding study affected the growth, production performance and changed phenotypic characteristics of crossbred offspring. The use of four breeds (indigenous, exotic, local developed and commercial) in this study was intended to complement desirable genetic characteristics with different abilities, to develop the local egg strain that is productive. The design of these study benchmarked on the study of (Padhi, Chatterjee & Rajkumar, 2014), who emphasised that, crossbreeding of exotic chicken breeds and indigenous chicken breeds is important to many countries that need to develop their local productive chicken breeds.

5.2 Growth performance of F1 crossbreeds and pure breeds

The body weight is an important trait used in poultry industry to measure the growth performance of broiler breeders, layers, and broilers during rearing. The local developed dual-purpose breed (Potchefstroom Koekoek) had the highest mean body weight at the age of 18 weeks compared to other breeds while White Leghorn recorded the lowest body weight among all breeds. The better performance of dual-purpose chicken breed was also achieved by Black Olympia dual-purpose chicken breed that performed better on body weight gain compared to indigenous strain and exotic strain across all growing stages from 0 to 20 weeks of age (Ogbu, Udeh & Nwakpu, 2012). The outstanding performance of Potchefstroom Koekoek and Black Olympia resulted from a better feed conversion ratio. The lower body weight of White Leghorn was also reported by Saadey et al., (2008) where it attained the lowest body weight of 1 472 g at the age 5 months compared Foyoumi local breed (1 561 g) and Sanai local breed (1 512 g) and Rhode Island Red (1 557 g). The lower body weight of White Leghorn can be correlated to its small body frame compared to other exotic breeds like Rhodes Island Red. Despite its small body frame, White Leghorn is while known exotic layer strain that has been used vastly to develop commercial layer and dual-purpose breeds in developing countries.

The indigenous NN breed attained almost similar body weight of the commercial Lohmann Brown with no significant difference ($p > 0.05$) due to its competitive body structure that is equivalent to many exotic breeds. Similar performance was achieved in Botswana where there was no significant difference in growth performance between NN and local chicken breed (Thutwa et al., 2012). However, different results were attained in Bangladesh, where NN had superior body weight and feed conversion ratio compared to its counterpart indigenous full-feathered chicken breed (Islam & Nishibori, 2009). Another constant high growth performance was achieved by NN compared to normal chicken breeds from 0 to 6 weeks of age at Hyderabad in Southern region, India (Rajkumar et al., 2011).

The South African dual-purpose (PK) and indigenous (NN) chicken breeds achieved the highest body weight compared to exotic White Leghorn in the current study. However, Sebola et al., (2015) attained contradicting results on performance of the exotic breed, Black Austrolop which had better growth performance than two South African breeds; Potchefstroom Koekoek and Ovambo. Similar trend was observed at Bangladesh when the exotic Rhode Island Red attained the highest body weight compared to two local breeds, Desi and Fayoumi at the age 20 weeks. The two local breeds Desi and Fayoumi consumed less feed and gained low body weight compared to Rhodes Island Red that consumed more feed and gained better body weight which differed significantly ($p < 0.05$) (Khawaja et al., 2012). The Lesotho local breed cocks had inferior growth with body weight (2 350 g) compared New Hampshire with (3 572 g) and Rhode Island Red (2 962 g). The Lesotho hens had competitive results where there was no significant difference ($p > 0.05$) when compared to Rhodes Island Red and New Hampshire hens (Nthimo et al., 2006).

Potchefstroom Koekoek dominated the growth performance on its F1 crossbred offspring. The inheritance of the heaviest body weight on crossbreed was noticed on PKLB and its reciprocal LBPK. The crossbreeding between PK and LB yielded the highest growth performance compared to crossbreeding of PK with other breeds. The PKLB yielded 177 grams more than LB pure breed, showing ability of

PK to improve body weight. This results are supported by Razuki & Al-Shaheen (2011), where the Iraqi local Brown line crossbred with New Hampshire (BR x NH) performed better than other crossbreed and pure breeds. The performance of PKLB, supported the objective one of the current study, by attaining the highest body weight compared to all other crossbreeds.The good growth performance of PKLB is supported by Rasheed, (2017), who discovered that the crossbreeding of indigenous (Fulani ecotype) and exotic breed (Rhodes Island Red) improved production performance of crossbreed and reciprocal offspring to be better than the indigenous Fulani chicken breed.

5.2.1 Feed consumption and conversion ratio for F1 offspring during rearing

Feed conversion ratio was used as a second measure to assess the best performance of chicken, by looking at the lowest feed consumption with adequate body weight gain. The results differed on feed conversion ratio, LBPK led with FCR of 5.88 kg, followed by PKLB with FCR of 6.17 kg then LBNN with FCR of 6.78 kg. The similar trend of results were reported by Khawajaa et al., (2012) who observed that the indigenous Fayoumi chicken breed had the lowest FCR compared to Rhode Island Red on third position, while Rhode Island Red had better FCR than Fayoumi. The FCR had a strong correlation relationship with cumulative body weight gain and cumulative feed consumption in the current study. The results confirm that crossbreeding studies of indigenous chicken and hybrid vigour chicken had effects on the growth with improved productivity on the offspring of local and exotic chicken breeds. Padhi (2016), had different view about indigenous chicken crossbreeding, by emphasising that breeding programme targeting improvement of indigenous chickens should focus within the breed selection rather than crossbreeding with commercial breeds. However, Anim, (2011) had a concern about the economic efficiency due to the low return from substantial investment for ongoing genetic improvement by crossbreeding programmes across the world. The sequence of better FCR by LBPK and PKLB among all crossbreeds indicates the possibility of better economic benefit that may result from genetic improvement by crossbreeding of local PK breed and commercial LB breed.

5.2.2 Economic efficiency measure of F1 offspring genotypes during growth stage

The current study considered the feed cost for rearing and production as the main tool for the calculation of economic efficiency measure to select the productive F1 crossbred chickens. The current study considered feed cost, production input and production yield such as the highest body weight to determine the most economic efficiency breeds during rearing. Cumulative feed intake at the age of 18 weeks revealed a strong and significant relationship for FCR ($r = 0.813$; $p < 0.0001$) and for EEF ($r = 0.814$ and $p < 0.0001$). According to Chetroiu & Calin, (2013), the economic efficiency in agriculture must be based on knowledge of elements that characterize the production effort considering three main resources: optimal use of resources, production management and overall cost. The current study reveals that the most economic efficiency crossbreed during rearing from day old to 18 weeks of age was LBPK with R38.79 followed by PKLB with R40.76 and LBNN on third at economic efficiency of R43.17. The results support Ali & Hossain, (2010), who discovered that the economic performance of poultry farmers in Bangladesh are directly, linked to the production cost and level of production output.

Since point of layers are not selling on cost per kg like broiler chickens but on cost to produce one chicken. The LBPK crossbreed performance led to the recommendation that this breed is the best economic efficiency on growth performance during rearing. These results are in agreement with Anim, (2011), who emphasised that the principles of economic can be used as the best measure to understand the success and failures of animal breeding, in this regards LB x PK crossbreeding was successful. The most economic efficient crossbreed is LBPK as it is supported by Chetroiu & Calin, (2013) who described economic efficiency on animal performance as one of the criteria for scientific substantiation of decision-making.

5.3 Egg production performance for pure and crossbreed F1 offspring

The performance of pure breeds on egg production was led by commercial (LB) with 19.19 dozens, followed by exotic (WL) with 16.59 dozens, in the third position it was a local dual-purpose (PK) with 12.19 dozens and lastly indigenous (NN) with 11.67 dozens. The performance of crossbreeds on egg production was led LBWL with 18.56 dozens, in second position it was PKLB with 16.19 dozens and in third position it was LBPK with 14.59 dozens. The purpose of cross breeding the exotic and indigenous chickens was attained by actual performance of PKLB on growth rate and egg production. The reciprocal of Nigerian Light ecotype and Heavy ecotype (LE x HE) had superior egg production and was selected over its count part crossbreed (HE x LE) and pure line parents (Momoh, Ani & Ugwuowo, 2010).

The egg industry grade eggs according to the categories size in grams and cluster them as small, medium, large, extra-large and jumbo. Egg price differ according to their grade for an example, a dozen of medium sell at a higher price than small grade and sell at lower price than the large graded dozen. Normally egg size start as pullet egg then graduate to small, medium, large, extra-large and end with jumbo (Omid et al., 2013). The classification of egg sizes of PKLB on egg production per hen were distributed as follow; small 10.63%, medium 34,46%, large 44.69%, extra-large 7.75%, Jumbo 0.50% and cracks 1.98%. There was a significant difference ($p < 0.05$) on classification of eggs among the breeds. Sh et al., (2012), achieved the contradicting results whereby all egg production traits differed significantly at ($p < 0.01$) from different genotypes and their replicates. According to Khawaja et al., (2013), egg production is the primary trait to measure the economic benefit of genetic improvement of layers. Thus, how eggs are classified by standardised grade sizes and priced per class of grade determined PKLB as the most economic efficiency F1 crossbreed in the current study.

5.3.1 Economic factor measure of pure and crossbreed F1 offspring during egg production stage

Egg production farming like any other business is the balance ratio between the input and output. The lowest cost on unbalance diet should not be the key factor because it can lead to poor egg products that are not purchasable on the market or small quantity that is not profitable. Fundo & Lafayette, (2015) determined the economic efficiency of contracted farmers by subtracting the operational cost from revenue. The financial working for economic factor on egg production showed that for every R1 spent there was loss of –R0.51 or 51% loss on PKNN looking at production percentage of the entire period of trial. The NN positioned itself to the in third negative position of financial loss with R0.11 or 11% loss. The LB had remarkable good ratio of 53%, followed by WL with 59%, LBWL with 64% and PKLB with 68%. This ratio indicated that LB was the most financial efficient with consideration of feed cost, for every rand spent on feed with an estimate of R0.47 can be expected as gross margin.

The LBWL was higher than WL with mean production per hen. The results for economic factor revealed that WL is better than LBWL. The results further revealed that for every rand spent on WL farmer can get an estimate R0.41 as margin while LBWL stand at R0.36 margin per rand spent on feed as input. The PKLB was the second crossbreed with better economic factor at the margin of R0.32 for every rand spent on feed. The crossbreeding between PK x NN and NN x PK was not successful while PK x LB and LB x WL where the most successful when measured on economic benefit principles. This variation of results is supported by (Anim, 2011), who emphasised that best measure to understand the success and failures of animal breeding can be achieved by the principles of economic benefit. In this regard, the three F1 crossbreed chickens that perform on economic efficiency for egg production were LBWL with the margin of R0.36, follow by PKLB with margin of R0.32 third position held by WLPK with R0.30 per rand spent on feed as an input. The purpose the crossbreeding exotic and indigenous chickens is to combine the abilities of these strains to develop adaptive productive crossbreed chicken for local use. The PKLB was selected as the best performed F1 crossbreed from local and exotic breed, based on its better growth and egg productivity, financial efficiency on the purpose of crossbreeding exotic and local chickens.

5.4 Phenotypic characteristics

Crossbreeding results increased heterozygosity and tended to cover up recessive genes and decreased the breeding purity. Crossbreeding had eliminated or suppressed some genes that relate to phenotypic characteristics of one or both families in their F1 offspring in the current study. Phenotypic effects of crossbreeding resulted to change of some physical characteristics on F1 crossbreed genotype. According to Peeters et al. (2012), the genetic parameters showed to be highly depended on animal phenotype thus supported by the phenotypic characteristics of chicken feathers with different colours according to the breed in the current study. Crossbreed often suppress or express the dominance of a particular colour on the offspring if compared to the sire or dam. In the current study, NN showed strong dominant of feather colour distribution to all its crossbreed offspring from LB, PK and WL. The clear notification of feather colour suppression and multiple colour expression of one breed is expected to have high impact on other breeds. The effects of crossbreeding on phenotypic characteristics was noticed on all NN F1 offspring and stay with naked neck irrespective of sire or dam use for crossbreeding. The NIFA-NSF-Phenomics, (2011) reported that prediction of phenotype from genotype is generally a difficult due to larger number of genes, however, in the current study phenotype of NN on feather colour distribution seemed to make prediction easier. There were high levels of colour inheritance by WLLB from the White Leghorn sire, while Lohmann brown dam colour was suppressed. The chicken breeds with one colour can lead to prediction of which breeds were used to produce a particular offspring which is not possible on breeds like NN with multiple feather colours.

White Leghorn is well known by its big comb that lie horizontally over the head. The results showed that there is an expression of this specific gene related to comb of WL in most of its offspring. Enormous improvement of wattles was noticed on WLNN females with an improvement of 82.52% compared to its female parent NN, and led to overall heterosis of 21.82% for both sexes. Habig, Geffers & Distl, (2012) reported that two-layer lines LSL and LB differed with gene expression despite their similar size of egg production. Clearly crossbreeding had effects on phenotypic characteristics of the crossbreed offspring by either improving or suppressing certain character including the capability of function from sire or dam.

5.4.1 General combining ability (GCA), SCA, HV and heterosis for growth performance of F1 genotypes

The heritability of some gene was noticed between offspring of NN x LB crossbreed and LB x NN crossbreed. The LBNN F1 male had a slightly higher variables than NNLB though NN pure male dominated in most variables of body structures. There was evidence of improvement by NN sire whereby, most body structure variables for NNWL were higher than WLNN. This showed that WL sire body weight contributed to the lower body weight of its offspring. The results showed that the body weight of dam influenced the maternal inheritance of its offspring. Similar pattern was observed on production performance with consistence of maternal body and specific combined ability between sire and dam. The gene played a fundamental role on the inheritance and revealed by genes between pure breeds, crossbreeds and reciprocal.

The PKWL had large comb due to influential gene from WL that make comb tissue to be dominant on its offspring. Hence, the heterosis results revealed an improvement on the size on PKWL male at 12.93% and female at 63.57% with the overall mean of both sexes at 25.79%. The WLPK male suppressed heterosis by -1.17%, with an increase of 20.55% on females compared to its female PK parent. The genetic behaviour for crossbred animals is divided into dominant inheritance and recessive inheritance (Zhe, 2012). Both genes can be inherited from either sire or dam, as it was observed that WL female chickens dominated NNWL F1 offspring with maternal ability of egg production. General combining ability for NNWL was -20.50% with suppressed maternal ability of -25.13%. The results showed that used indigenous breed, NN cocks on exotic layer suppressed egg laying ability of WL hens. The introduction of WL sire on NN dam improved the egg production ability of their offspring. The purpose of crossbreeding is achieved when an animal with poor maternal ability is crossbred with animal of good maternal ability to improve its production function.

The local dual-purpose breed dominated its offspring crossbred from three pure genotypes used on most measured phenotypic body structures (body weight, body length, wing span chest circumference and shank length). The PK was highly significant ($p < 0,005$) to many breeds due to its heavy sire body weight. Saadey et al., (2008) reported that the local Sinai breed has the heaviest body weight compared to other three pure breeds. The improvement on body structures by PK was noticed in all crossbred especially on LB. The hybrid vigour for PKLB was 0,87% compared to the improved weight of LBPK by 12.98%. The PKLB body weight was 177 g above the LB pure breed. This results indicated the ability of PK on the improve body weight of its crossbreed offspring from LB. Saadey et al., (2008) reported that Sinai crosses (F x S and S x WL) achieved the heaviest body weight at all ages compared to other crossbreeds with positive and high heterotic percentage discovered on S x WL at all ages. The GCA, SCA and HV for phenotypic characteristics measure was significant at ($p < 0.05$) in most PK offspring compared to offspring of other breeds due to heavy body weight 2 561 g of PK sire. The PKWL showed consistent results on body weight SCA by high mean compared to its reciprocal WLPK. The PK dam contributed to the improvement of WL crossbreed phenotypic body structures. The small body structures of WL improved its F1 offspring due to its crossbreeding with PK.

According to Fairfull, Gowe & Emsley, (2007), the GCA and SCA effects for all production traits like sexual maturity, body weight, feed consumption and egg production are link to dominance of sire or dam abilities. Saadey et al., (2008) discovered that Rhode Island Red had the lowest GCA over a period of four months while Sinai showed the positive effect of GCA for the entire study period (six months). The effect of phenotypic body structures measured for the sum and mean square showed high level between the variables. The analysis of phenotypic body structures was performed to establish other variable traits the can be considered when selecting the pullet at laying point for high productivity and economic efficiency. The GCA for NNPK was at -36.50 while PKNN was worse at -82.50 during growth performance. The huge difference between weight of male and female for NN and PK breeds contributed to negative GCA results. These results were interpreted further with correlation of growth rate, feed intake during rearing, laying period and genetic results to the cause of production suppression. The crossbreeding improved other breeds while suppressing one that has capability of particular function.

5.4.2 GCA, SCA, HV and Heterosis on egg production of F1

The selection of crossbreed animal is based on GCA, on improved performance of particular offspring resulting from heritable traits from sire or dam. Bosworth & Waldbieser (2014), used the same principle for selection of blue catfish whereby, a fair intensive selection of blue sire was rapidly used to improve hybrid progeny performance. It was further indicated that the small effects of dam and sire for incidence of deformities in hybrid catfish revealed little genetic basis for observed deformities. The low genetic distances indicated a close genetic relationship whereas large genetic distances indicated a more distant genetic relationship on Cameroon local chickens versus European and Asian chicken breeds (Keambou et al., 2014).

The commercial layer breed laid the highest number of eggs 230 followed by its offspring LBWL with 223 eggs at the age of 65 weeks. The LBWL produced an average number of eggs produced by both parents. The local developed dual-purpose breed (PK) also produced high number of eggs when crossbred with LB sire or dam. The crossbreed PKLB held fourth position with production of 194 eggs and reciprocal LBPK fifth position production of 175 eggs. This suggested that the 3-way crosses would be effective in improving annual egg production yield. The 3-way back crosses was recommended as an effective breeding where (Mandarah x Lohmann Brown) F1 offspring was backcross with Lohmann Brown for improvement of egg production (El-Ghar, Ghanem & Aly, 2010).

The crossbreeding of PK x LB revealed that improvement on growth and egg production which support Padhi, (2016) who emphasised that the improvement of African indigenous chicken breeds using high producing European breeds was seen as quickest way to achieving genetic improvement that can increase egg or meat production on offspring. Only two crossbreeds that highly performed on egg production and had positive GCA (PKLB score 5.50 and LBWL 8.5) other 10 crossbreeds and reciprocal yielded negative GCA. High positive specific combining ability ranging from 143 to 214 was achieved in all offspring egg production at the age of 44 weeks. Sh et al., (2012) reported a good positive specific combining ability (SCA) effect values for egg numbers at the age of 240 days (34 weeks) on four over eight hybrid breeds. Two crossbreeds in the same study reflected positive SCA at the age of 52 weeks. The indigenous chicken breed, NN hens produced 70% of what WL hens produced. The achieved general combining ability for NNWL was -20.50 with suppressed maternal ability of -25.13%. The results showed that the indigenous chickens, NN cocks on exotic layer suppressed egg laying ability of WL hens. The WLNN hens achieved the GCA of -4.50, with great improvement of maternal ability by 17.86%.12. Sh et al., (2012), obtained similar results on LB selected WL where it revealed the lowest negative insignificant GCA values -2.4, -2.1 and -3.1. The introduction of WL sire on NN dam improved the production ability of their offspring.

The GCA and SCA results can be related to the maternal effects that was discovered on phenotypic growth traits. The NN had poor maternal ability for egg production compared to LB. The results showed that the ability of LB hens on egg production was suppressed by crossbreeding with NN. The GCA was negative due to the combined actual performance of parents where NN produced 61% of LB`s actual egg production. The LB cocks improved the egg laying ability of WL hens. The GCA for LBWL recorded 8.50 with significant improvement of maternal egg laying ability by 12.06%. The LBWL achieved a high special combining ability of egg production from sire and dam higher than any other offspring produced in the current study. The LBWL score high on GCA and SCA allow fair selection of this crossbreed based on its highest egg production performance as done by (Bosworth & Waldbieser, 2014). The LBWL produced more eggs and it became most economic efficient crossbreed than other crossbreeds that come from egg laying strain without indigenous line. The WL achieved a better economic efficiency than all other breeds followed by LBWL crossbreed. The economic outcome revealed that every rand farmer spent on WL can get an estimate R0.41 as margin while LBWL stand at R0.36 margin per rand spent on feed as input. The results about the two breeds (PK and LB) revealed the improvement of production on PK hens when crossbred with LB cocks. The crossbreeding of commercial egg laying hen with local breed led to the suppression of a particular production gene. The PKLB is the first best crossbreed from local and exotic breeds with better economic efficiency factor at the margin of R0.32 for every rand spent on feed. The results are in accordance with observation of Padhi, (2016), that few major economic traits improved crossbreed compared to indigenous breed.

5.5 Egg quality

The analysis of exterior and interior quality was fundamentally important on the current study for further observation of maternal inheritance among breeds. The exterior egg quality variables included egg weight, egg circumference, egg length, egg width and eggshell weight. The interior variables covered yolk and albumen measures.

5.5.1 Exterior egg quality measures

The circumference for eggs was measured lengthwise and width wise. The NNWL held fourth position on the production of jumbo and fifth position on production of X-large. This breed held the greatest egg mean weight with random selected eggs. The consumer demands of high quality and safe food with reduced chemicals and antibiotics led to the initiative of current crossbreeding study and others across the world. According to Padhi (2016), the increase requirement for safe food and high quality products including strong eggshell in poultry, led breeders and researchers to development breeds that are genetically resistant to pathogens.

Lohmann Brown laid brown egg shell, WL laid white egg shell while PK and NN laid medium brown eggshell. The eggshell colours for crossbreed were two to five. White Leghorn dominated most colours of egg shells with white colour though not all eggs recorded pure white. More than 100 years ago, the researchers discovered different colours of eggs from crossbreeding of Brown Leghorn (BL) sire and Langshan dam. The colour of egg shells were characterised by dominance of white and light tinted colours (Punnett, Major & Bailey, 1911). The study showed high levels of WL capability on dominance of phenotypic feather colours in all its crossbreeds. Further dominance was observed on eggshell colours for crossbred and reciprocal offspring of WL. In the current study the brownish egg shells were recorded for WLLB, WLPK and LBWL crossbreeds. The WLLB had lighter eggshell in colour than LBWL. The WLNN and NNWL had lighter egg shell than PKWL, LBWL, WLLB and WLPK. The maternal inheritance between the indigenous, exotic and commercial layer breeds was pronounced on eggshell colour of other breeds and suppressed on others.

South African indigenous chickens naturally lay eggs with light brown shells and commercial table egg shell are brown. The colour of eggshell from crossbreeding will remain important since South Africa is multi-cultural diversity country open for migrants and visited by diversify people coming from different parts of the world. Culture beliefs and lack of knowledge about particular products often make people doubtful to consume something they do not know. Some consumers prefer eggs of specific eggshell colour and yolk. Therefore, the final decision should fairly be based on production performance, economic efficiency, consumer quality and safe products. Honkatukia et al., (2013) discovered five genomic regions that affected eggshell colour of F2 population in chromosome 3 and 6. On the other hand, Wolc et al., 2014 reported that qualitative traits locus that affected shell colour are in chromosome 2.

The NNWL had the highest 8.292 g for eggshell weight and 21.063 g for yolk weight. The WLLB was in the second position while LBLB became third on eggshell weight. The yolk weight, eggshell weight and eggshell thickness did not follow the same trend or position on sixteen genotypes. The study revealed that the albumen part carried the largest weight of the whole egg. In the current study, the albumen weight ranged from 51.44% to 58.72%, yolk weight ranged from 29.65% to 36.17% and shell weight ranged from 11.14% to 14.36% at the age of 60 weeks. The Padhi, Chatterjee & Rajkumar, (2014) observed that weight for yolk was 28.52%, for eggshell was 8.15% and for albumen was 63.33% at the age of 40 weeks. There was no systematic sequence on distribution of egg weight. The results showed that the median egg weight could have greater percentage of albumen distribution than the bigger weight egg. The eggs that weighed 58.75 g had the highest albumen weight representing 58.72% compared to eggs that weighed 62.08 g with albumen weight of 55.17%. Wolc et al., (2014) discovered that the qualitative traits locus affected overall size rather than a direct relationship with yolk weight. The yolk weight measurements at early and late age were located on chromosomes 1 and 3. The LBPK held the first position with the highest eggshell thickness of 0.456 mm, followed by LBWL with 0.440 mm and in the third place there was LBLB with 0.424 mm. Eggshell strength is the fundamental measure that need to be considered for selection of the breed because thicker shells do not break easily on supply chain process to final consumer. The LBWL continued to lead with important traits such as egg production that are required for the selection of laying breed, however, it was not preferred due its development from exotic breeds.

5.5.2 Interior egg quality measures

The yolk colour was studied to determine if the maternal inheritance expressed or suppressed some of genes that influenced the colour of yolk from either sire or dam. The results revealed that about 58% of eggs measured from commercial (LB) were in colour code 5, 25% were in code 6 and 17% were in colour code 7. The indigenous breed (NN) had the darker yolk colour than commercial breeds. Only 8% of measured eggs scored in colour code 7. Due to the stable marketing and continuous availability of commercial egg on retail store, South African consumers prefer eggs of light colour and they become uncomfortably with darker yolk. The international consumer surveyed on consumer egg preferences showed that consumer preferences for yolk colour are subjective and vary from country to country (Gerber, 2005). Majority of NN egg yolk had darker colour. The LB score lighter yolk colour compared to NN, with 33% scored in code 8, 42% scored in code 9 and 17% in code 10. The offspring produced interesting results whereby both LBNN and NNLB scored 67% in colour code 6. The results showed the slight suppression of maternal ability of laying light yolk colour by LB with more suppression of darker yolk colours from NN. The results showed that the maternal ability of both parents was compromised, with slight upper adjustment on PK and slight down adjustment on NN. It is still not clear what caused the slight shift experienced in some breeds.

5.6 CONCLUSION

The study was concluded on the hypothetical outcomes. Potchefstroom Koekoek dominated the growth performance with the inheritance of the highest body weight mean of 2 079 g on its offspring between PK sire and LB dam (PKLB). The best performers on FCR were LBPK (5.78), PKLB (6.08) and LBNN (6.44). Similar positions were attained for cost of rearing by same breeds, LBPK rear at R38.79, PKLB at R40.76 and LBNN at R43.17. However, the positions changed on economic efficiency factor when one pure breed was in top three performers. The PKLB attained first position by gaining highest grams (51.02 g) for rand expenditure on feed. In the second position there was LBPK with 50.81 g and in third position there was PKPK with 49.06 g. The outcome of crossbreeding led to rejection of hypothesis 1, since PK weight had positive effects on the growth performance and economic efficient on rearing of its offspring, PKLB and LBPK compared to other crossbreed and pure breeds.

The most performed F1 crossbreeds on egg production were as follow; LBWL with 223 eggs, PKLB with 194 eggs and LBPK with 175 eggs at the age of 65 weeks. The lowest cumulative feed consumption was strongly correlated to feed cost due the amount of rand spent on one kg of feed. The WLPK held first position with the lowest cumulative feed consumption of 35.280 kg at the cost of R217.68 at the age of 65 weeks. The PKNN held second position with 38.953 kg at cost of R240.34 and LBPK was in third position with 39.363 kg of feed at cost of R242.87. The crossbreeds that has the highest return in South African rand were as follow; LBWL return of R430.02, PKLB with R365.67 and LBPK with R329.24. The economic efficiency factor for this study measures the cumulative feed cost from age of day 1 to the termination of production versus the overall return from all eggs at termination. The LBWL held the first position for economic efficiency factor by margin of R0.57, followed by PKLB with margin of R0.47 and WLPK with margin of R0.42 for every rand spend on feed. The LBPK held the fourth position of economic efficiency factor, close to its third position on the measure of cumulative feed intake and cost variables. The outcome of egg production and economic efficiency factor lead to the rejection of hypothesis 2. The F1 offspring differed with egg production, feed consumption and economic efficiency factor. The best performing breed considering production variables, were LBWL in first position, PKLB second position and WLPK in third position.

Crossbreeding had an effect on the phenotypic characteristics including the body structure variables like body weight, body length and chest circumference. The most of improvements were noticed on WL crossbred offspring was whereby WLPK score 419 g and PKWL score 548 g above the WL body weight. The big improvement on chest circumference was noticed on PKWL with 23 mm and NNWL with 30 mm. The improved body length was notice on NNWL with 23 mm longer than White Leghorn.

The NNWL cocks had the longest comb (109.2 mm) followed by LBWL with 104.4 mm and WLPK 101.2 mm. The length of hens' comb was the longest for NNLB with 48 mm followed by NNWL with 44 mm and PKNN 3rd 43.8 mm. The comb height for the cocks was led by PKWL with 57.4 mm, followed by NNWL with 54.6 mm and LBPK with 52.6mm. The comb height for hens was led by NNLB with 22.6 mm, followed by NNWL 21.8 mm and PKWL 21.4 mm. For the wattles length of cocks, NNWL led with 52 mm followed by LBWL with 51.8 mm and PKPK with 51.4 mm. The wattles length for hens was led by NNLB with 28 mm, followed by LBWL 27.2 and PKLB with 23.8 mm.

Naked neck recorded nine multiple feather colours, LB had two colours while PK and WL individually had one standard colour. The crossbreed between NN and LB produced 20 colours from purebred, crossbred and reciprocal offspring. The crossbreeding between NN and WL produced 15 feather colours from all offspring. The outcome of the study led to the rejection of hypothesis 3. Crossbreeding had effects on the phenotypic characteristics of offspring on head, feather, body structures and maternal bodies related to egg production.

The general combine ability, specific combine ability, hybrid vigour and heterosis were performed to establish how breeds complimented each other on phenotypic characteristics. The crossbreeds that lead with GCA on different variable were PKNN with 253 g on body weight, body length PKLB 30 mm and chest circumference by LBPK with 48 mm, 2nd PKNN 32 mm and 3rd NNLB 31 mm. The SCA, for body weight was led by PKNN with 1 914 g, body length by NNPK with 404 mm, wingspan by NNPK 522 mm, chest circumference by PKNN with 321 mm.

The calculation for hybrid vigour (HV) on body weight was led by WLPK with 41.46 g, body length by PKLB 7.21 g, wingspan led by the LBPK with 2.21 mm, chest circumference by LBPK with 17.17 mm. The heterosis body weight led by PKNN with 2 061.8 g, body length by PKLB 309.32 mm, wingspan was observed on PKLB 397.92 mm, chest circumference, LBPK 268.05 mm. The outcomes of this study allow the rejection of hypothesis 4, due to the differences phenotypic characteristics that were discovered on GCA, SCA, heterosis and HV. The GCA, SCA, heterosis and HV for body weight, body length, wingspan, chest circumference and shank length differ among the crossbreeds.

The crossbreeds differed on graded egg distribution percentage per category of small, medium, large, extra-large and jumbo. The weight of the yolk, albumen, eggshell and eggshell thickness differ among the crossbreeds. White Leghorn dominated genes of its offspring by passive phenotypic gene that were expressed on phenotypic characteristics. White Leghorn dominated eggshell and yolk colours with all its offspring. The yolk colour study revealed that the maternal inheritance had expressed or suppressed some of genes that influenced colour of yolk from either sire or dam. White Leghorn measured the lowest yolk height and was highly significant $p < 0.0001$ to 14 breeds followed by WLPK that was highly significant to 13 breeds. The yolk weight, albumen height differed among the breeds. In the current study, the albumen weight ranged from 51.44% to 58.72%. In addition, yolk weight ranged between 29.65% and 36.17% and shell ranged between 11.14% and 14.36%. The variation of egg parameters from production of different F1 crossbreeds led to the rejection of hypothesis 5 of the current study. The weight of eggs, shell colours and yolk colours of the crossbreed showed inheritance of dominated genes from a particular parent when correlated to eggs of purebreds.

Crossbreeding of exotic, commercial and indigenous chickens had an effect on the growth, maturity, production and phenotypic characteristics of offspring. The aim of the study was achieved by selection of PKLB based on its outstanding results of production performance, economic efficiency and egg quality parameters.

5.7 RECOMMENDATIONS

There is need to do further selections for NN to categorise breed into two or three colours to avoid nine colours identified in the current study. After the selection and grouping by common colours, further selection should focus on growth and production performance to conserve pure genotype of indigenous chickens like NN. Potchefstroom Koekoek and other pure chicken breeds that are conserved at ARC should be continuously selected for growth and production performance, disease resistance and environmental adaptation. The PKLB performed better than other chicken crossbreeds under intensive environment, therefore, there is need to test this crossbreed under semi-scavenging system to determine if these crossbreed can address the gap of organic eggs in the market. There is need for continuous chicken crossbreeding research studies up to F4 generation to develop local hybrid chickens for local farms specialising in organic and free-ranging productions. Collaborative research among researchers, institutions, research facilities and poultry industry is required to establish local hybrid breeds.

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APPENDIXES

APPENDIX A: EXAMPLE OF MONTHLY DATA RECORDING FORM

Data capturing form: Daily Eggs, Mortality, Feeding, Temperature and weekly Body weights								No. Chick	Female	Male
			Breed	NN X PK	Age of chickens			24	21	3
Date	**Day of week**	**EGGS Daily**	**Feed add**	**Left over**	**Days**	**Weeks**	**Mor tality**	**No. Chick**	**Weigh t**	**Sex**
01 June 2016	Wednesday			25,8	**101**					
02 June 2016	Thursday				**102**			10	17,4	M & F
03 June 2016	Friday				**103**					
04 June 2016	Saturday				**104**					
05 June 2016	Sunday				**105**					
06 June 2016	Monday		5,00		**106**					
07 June 2016	Tuesday				**107**					
08 June 2016	Wednesday		49,3	1,8	**108**			10	18,7	M & F
09 June 2016	Thursday				**109**					
10 June 2016	Friday				**110**					
11 June 2016	Saturday				**111**					
12 June 2016	Sunday				**112**					
13 June 2016	Monday				**113**					
14 June 2016	Tuesday				**114**					
15 June 2016	Wednesday			25,9	**115**			10	15,9	M & F
16 June 2016	Thursday				**116**					
17 June 2016	Friday				**117**					
18 June 2016	Saturday				**118**					
19 June 2016	Sunday				**119**					
20 June 2016	Monday				**120**					
21 June 2016	Tuesday		50,4		**121**					
22 June 2016	Wednesday			45,3	**122**			10	16,1	Male
23 June 2016	Thursday				**123**			9	13,3	Female
24 June 2016	Friday				**124**					
25 June 2016	Saturday				**125**					
26 June 2016	Sunday				**126**					
27 June 2016	Monday				**127**					
28 June 2016	Tuesday				**128**					
29 June 2016	Wednesday			140	**129**					
30 June 2016	Thursday				**130**					

APPENDIX B: PHYSICAL PHENOTYPIC CHARACTERISTICS

Cross Breeds: ……………………………………………….Sex:………………………

Chicken No:	**1**	**2**	**3**	**4**	**5**
Sex	F / M	F / M	F / M	F / M	F / M
Body weight (g)					
Body length					
Wing span (mm)					
Chest circumference					
Shank length (mm)					
Shank circumference					
Shank colour	W / Y / B / G / Bl / Br / L / other…..	W / Y / B / G / Bl / Br / L / other…..	W / Y / B / G / Bl / Br / L / other…..	W / Y / B / G / Bl / Br / L / other…..	W / Y / B / G / Bl / Br / L / other…..
Middle toe size					
Comb type	S / P / R / W / C / St / D / V / Dob / other……	S / P / R / W / C / St / D / Dob / other……	S / P / R / W / C / St / D / Dob / other……	S / P / R / W / C / St / D / Dob / other……	S / P / R / W / C / St / D / Dob / other……
Comb size Length					
Comb height (mm)					
Wattles size length					

Wattles size width					
Ear colour	Red / White	Red / White	Red / White	Red / White	Red / White
Eye colour					
Feather colour	W / Bl / B / R / Wh / Br / C / other……..	W / Bl / B / R / Wh / Br / C / other……..	W / Bl / B / R / Wh / Br / C / other……..	W / Bl / B / R / Wh / Br / C / other……..	W / Bl / B / R / Wh / Br/ C / other……..
Feather morphology	N / F / S	N / F / S	N / F / S	N / F / S	N / F / S
Feather distribution	N / Nn / Fs&f / M&B / C / Vh / other………	N / Nn / Fs&f / M&B / C / Vh / other………	N / Nn / Fs&f / M&B/ C / Vh / other………	N / Nn / Fs&f / M&B/ C / Vh / other………	N / Nn / Fs&f / M&B/ C / Vh / other………
Body Feather Length mm					
Wing primary feather (mm)					
Wing secondary					
Tail Feather length (mm)					
Tail Feather width (mm)					
Ear lobe colour	W / R / W&R / other………	W / R / W&R / other………	W / R / W&R / other………	W / R / W&R / other………	W / R / W&R / other………
Opening pelvic bone (mm)					

DEFINITIONS OF TERMS

Comb type: S = Single; P = Pea; R= Rose; W= Walnut; C = Cushion; St = Strawberry; D = Duplex; V = V-shaped; Dob = Double.

Comb size: S = Small; M = Medium; L = Large.

Shank colour: W = White; Y = Yellow; B = Black; G = Green; Bl = Blue; Br = Brown; L = Lead.

Feather colour: W = White; Bl = Blue; B = Black; R = Red; Wh = Wheaten; Br = Brown; C = Combination.

Feather morphology: N = Normal; F = Frizzle; S = Silky.

Feather distribution: N = Normal; Nn = Naked neck; Fs&f = Feathered shank & feet; M & B = Muffs & Beard; C = Crest; Vh = Vulture hocks.

Ear lobe colour: W = White (not pigmented); R = Red; W&R = White & Red.

APPENDIX C: EGG QUALITY DATA CAPTURING FORM

Breed	Egg no	Egg shell colour	Weight	Tape length C	Tape width C	Calliper Length	Calliper width	Shell weight	Shell thick	Albumen spread length	Albumen spread width	Albumen height 1 yolk	Albumen height 2	York spread	York height	York colour no:	York weight	Blood spot
NNNN	1																	
NNNN	2																	
NNNN	3																	
NNNN	4																	
NNNN	5																	
NNNN	6																	
NNNN	7																	
NNNN	8																	
NNNN	9																	
NNNN	10																	
NNNN	11																	
NNNN	12																	

APPENDIX D: PAIR SEX OF BODY LENGTH (MM) FOR EACH BREED COMPARED WITH ALL OTHER BREEDS.

	LB	LBLB	LBNN	LBPK	LBWL	NN	NNLB	NNNN	NNPK	NNWL	PK	PKLB	PKNN	PKPK	PKWL	WL	WLLB	WLNN	WLPK	WLWL
LB		0.725	0.508	0.929	0.011	0.006	0.167	0.818	0.250	0.840	0.687	0.004	0.170	0.262	0.185	0,014	0.455	0.690	0.683	0.073
LBLB	0.725		0.788	0.820	0.013	0.058	0.371	0.614	0.489	0.896	0.981	0.026	0.375	0.505	0.146	0,018	0.342	0.515	0.961	0.063
LBNN	0.508	0.788		0.620	0.006	0.112	0.531	0.440	0.672	0.690	0.739	0.050	0.536	0.690	0.086	0,008	0.223	0.358	0.826	0.034
LBPK	0.929	0.820	0.620		0.023	0.031	0.262	0.782	0.358	0.922	0.811	0.014	0.266	0.371	0.220	0,036	0.469	0.672	0.782	0.103
LBWL	**0.011**	**0.013**	**0.006**	**0.023**		0.000	0.001	0.045	0.002	0.018	0.004	0.000	0.001	0.002	0.291	0,596	0.119	0.063	0.011	0.515
NN	**0.006**	0.058	0.112	**0.031**	**0.000**		0.385	0.014	0.270	0.041	0.019	0.496	0.380	0.258	0.000	0,000	0.003	0.008	0.066	0.000
NNLB	0.167	0.371	0.531	0.262	**0.001**	0.385		0.163	0.839	0.,306	0.291	0.180	0.994	0.820	0.019	0,001	0.066	0.123	0.398	0.006
NNNN	0.818	0.614	0.440	0.782	**0.045**	**0.014**	0.163		0.232	0.708	0.576	0.007	0.165	0.242	0.342	0,074	0.655	0.884	0.580	0.175
NNPK	0.250	0.489	0.672	0.358	**0.002**	0.270	0.839	0.232		0.411	0.411	0.123	0.845	0.981	0.033	0,002	0.101	0.180	0.520	0.011
NNWL	0.840	0.896	0.690	0.922	**0.018**	**0.041**	0.306	0.708	0.411		0.899	0.019	0.310	0.425	0.186	0,027	0.411	0.603	0.858	0.,084
PK	0.687	0.981	0.739	0.811	**0.004**	**0.019**	0.291	0.576	0.411	0.899		0.010	0.295	0.428	0.098	0,004	0.283	0.467	0.936	0.034
PKLB	**0.004**	**0.026**	**0.050**	**0.014**	**0.000**	0.496	0.180	**0.007**	0.123	**0.019**	**0.010**		0.178	0.117	0.000	0,000	0.002	0.004	0.029	0.000
PKNN	0.170	0.375	0.536	0.266	**0.001**	0.,380	0.994	0.165	0.845	0.310	0.295	0.178		0.826	0.020	0,001	0.067	0.125	0.402	0.006
PKPK	0.262	0.505	0.690	0.371	**0.002**	0.258	0.820	0.242	0.981	0.425	0.428	0.117	0.826		0.035	0,002	0.106	0.188	0.536	0.012
PKWL	0.185	0.146	0.086	0.220	0.291	**0.000**	**0.019**	0.342	**0.033**	0.186	0.098	**0.000**	**0.020**	**0.035**		0,490	0.614	0.421	0.133	0.684
WL	**0.014**	**0.018**	**0.008**	**0.036**	0.596	**0.000**	**0.001**	0.074	**0.002**	**0.027**	**0.004**	**0.000**	**0.001**	**0.002**	0.490		0.204	0.106	0.016	0.825
WLLB	0.455	0.342	0.223	0.469	0.119	**0.003**	0.066	0.655	0.101	0.411	0.283	**0.002**	0.067	0.106	0.614	0,204		0.763	0.317	0.363
WLNN	0.690	0.515	0.358	0.672	0.063	**0.008**	0.123	0.884	0.180	0.603	0.467	**0.004**	0.125	0.188	0.421	0,106	0.763		0.484	0.226
WLPK	0.683	0.961	0.826	0.782	**0.011**	0.066	0.398	0.580	0.520	0.858	0.936	**0.029**	0.402	0.536	0.133	**0,016**	0.317	0.484		0.057
WLWL	0.073	0.063	**0.034**	0.103	0.515	**0.000**	**0.006**	0.175	**0.011**	0.084	**0.034**	**0.000**	**0.006**	**0.012**	0.684	0,825	0.363	0.226	**0.057**	

APPENDIX E: PAIR SEX OF WINGSPAN (MM) FOR EACH BREED COMPARED WITH ALL OTHER BREEDS.

	LB	LBLB	LBNN	LBPK	LBWL	NN	NNLB	NNNN	NNPK	NNWL	PK	PKLB	PKNN	PKPK	PKWL	WL	WLLB	WLNN	WLPK	WLWL
LB		0.809	0.825	0.482	0.007	0.054	0.608	0.873	0.323	0.048	0.007	0.030	0.069	0.747	0.375	0.197	0.057	0.163	0.405	0.000
LBLB	0.809		0.986	0.413	0.034	0.069	0.513	0.944	0.287	0.131	0.015	0.037	0.171	0.625	0.576	0.417	0.148	0.317	0.608	0.000
LBNN	0.825	0.986		0.423	0.033	0.073	0.525	0.958	0.295	0.127	0.016	0.039	0.165	0.638	0.564	0.405	0.143	0.309	0.596	0.000
LBPK	0.482	0.413	0.423		0.004	0.381	0.869	0.455	0.805	0.020	0.133	0.202	0.029	0.742	0.169	0.080	0.024	0.070	0.184	0.000
LBWL	**0.007**	**0.034**	**0.033**	**0.004**		0.000	0.006	0.029	0.002	0.540	0.000	0.000	0.451	0.009	0.118	0.102	0.498	0.261	0.108	0.049
NN	**0.054**	0.069	0.073	0.381	**0.000**		0.286	0.083	0.554	0.000	0.441	0.550	0.001	0.209	0.014	0.001	0.001	0.003	0.016	0.000
NNLB	0.608	0.513	0.525	0.869	**0.006**	0.286		0.560	0.680	0.031	0.091	0.150	0.044	0.869	0.226	0.118	0.036	0.099	0.244	0.000
NNNN	0.873	0.944	0.958	0.455	**0.029**	0.083	0.560		0.320	0.114	0.019	0.044	0.150	0.676	0.529	0.372	0.130	0.284	0.560	0.000
NNPK	0.323	0.287	0.295	0.805	**0.002**	0.554	0.680	0.320		0.010	0.223	0.303	0.015	0.564	0.105	0.042	0.013	0.040	0.115	0.000
NNWL	**0.048**	0.131	0.127	**0.020**	0.540	**0.000**	**0.031**	0.114	**0.010**		0.000	0.000	0.888	0.046	0.340	0.350	0.948	0.608	0.317	0.010
PK	**0.007**	**0.015**	**0.016**	0.133	**0.000**	0.441	**0.091**	**0.019**	0.223	**0.000**		0.976	0.000	0.060	0.002	0.000	0.000	0.000	0.003	0.000
PKLB	**0.030**	**0.037**	**0.039**	0.202	**0.000**	0.550	0.150	**0.044**	0.303	**0.000**	0.976		0.001	0.109	0.008	0,.001	0.000	0.002	0.010	0.000
PKNN	0.069	0.171	0.165	**0.029**	0.451	**0.001**	**0.044**	0.150	**0.015**	0.888	**0.000**	**0.001**		0.064	0.417	0.440	0939	0.711	0.390	0.007
PKPK	0.747	0.625	0.638	0.742	**0.009**	0.209	0.869	0.676	0.564	**0.046**	0.060	0.109	0.064		0.295	0.169	0.054	0.137	0.317	0.000
PKWL	0.375	0.576	0.564	0.169	0.118	**0.014**	0.226	0.529	0.105	0.340	**0.002**	**0.008**	0.417	0.295		0.868	0.374	0.659	0.962	0.000
WL	0.197	0.417	0.405	0.080	0.102	**0.001**	0.118	0.372	**0.042**	0.350	**0.000**	**0.001**	0.440	0.169	0.868		0.390	0.731	0.825	0.000
WLLB	0.057	0.148	0.143	**0.024**	0.498	**0.001**	**0.036**	0.130	**0.013**	0.948	**0.000**	**0.000**	0.939	**0.054**	0.374	0.390		0.654	0.349	0.008
WLNN	0.163	0.317	0.309	0.070	0.261	**0.003**	0.099	0.284	**0.040**	0.608	**0.000**	**0.002**	0.711	0.137	0.659	0.731	0.654		0.625	0.002
WLPK	0.405	0.608	0.596	0.184	0.108	**0.016**	0.244	0.560	0.115	0.317	**0.003**	**0.010**	0.390	0.317	0.962	0.825	0.349	0.625		0.000
WLWL	**0.000**	**0.000**	**0.000**	**0.000**	**0.049**	**0.000**	**0.000**	**0.000**	**0.000**	**0.010**	**0.000**	**0.000**	**0.007**	**0.000**	**0.000**	**0.000**	**0.008**	**0.002**	**0.000**	

APPENDIX F: PAIR SEX OF CHEST CIRCUMFERENCE (MM) FOR EACH BREED COMPARED WITH ALL OTHER BREEDS.

	LB	LBLB	LBNN	LBPK	LBWL	NN	NNLB	NNNN	NNPK	NNWL	PK	PKLB	PKNN	PKPK	PKWL	WL	WLLB	WLNN	WLPK	WLWL
LB		0.013	0.265	0.000	0.580	0.278	0.004	0.002	0.121	0.532	0.326	0.012	0.174	0.001	0.962	0.027	0.265	0.451	0.176	0.004
LBLB	**0.013**		0.233	0.124	0.009	0.109	0.708	0.593	0.417	0.107	0.092	0.967	0.328	0.425	0.035	0.000	0.002	0.133	0.324	0.000
LBNN	0.265	0.233		0.007	0.149	0.819	0.117	0.085	0.702	0.672	0.754	0.217	0.829	0.047	0.356	0.004	0054	0.755	0.835	0.001
LBPK	**0.000**	0.124	**0.007**		0.000	0.001	0.244	0.314	0.019	0.002	0.001	0.134	0.012	0.458	0.000	0.000	0.000	0.003	0.012	0.000
LBWL	0.580	**0.009**	0.149	**0.000**		0.151	0.003	0.002	0.069	0.308	0.176	0.008	0.098	0.001	0.602	0.206	0.627	0.258	0.099	0.046
NN	0.278	0.109	0.819	**0.001**	0.151		0.042	0.027	0.503	0.794	0.918	0.099	0.633	0.012	0.402	0.001	0.046	0.895	0.639	0.000
NNLB	**0.004**	0.708	0.117	0.244	**0.003**	**0.042**		0.873	0.236	0.047	0.034	0.739	0.176	0.672	0.013	0.000	0.001	0.061	0.174	0.000
NNNN	**0002**	0.593	0.085	0.314	**0.002**	**0.027**	0.873		0.179	0.032	0.022	0.622	0.131	0.792	0.008	0.000	0.000	0.042	0.129	0.000
NNPK	0.121	0.417	0.702	**0.019**	0.069	0.503	0.236	0.179		0.421	0.451	0.393	0.868	0.108	0.192	0.001	0.021	0.487	0.862	0.000
NNWL	0.532	0.107	0.672	**0.002**	0.308	0.794	**0.047**	**0.032**	0.421		0.860	0.098	0.523	0.016	0.617	0.015	0.133	0.911	0.527	0.003
PK	0.326	0.092	0.754	**0.001**	0.176	0.918	**0.034**	**0.022**	0.451	0.860		0.083	0.575	0.009	0.451	0.001	0.056	0.962	0.580	0.000
PKLB	**0.012**	0.967	0.217	0.134	**0.008**	0.099	0.739	0.622	0.393	0.098	0.083		0.308	0.449	0.032	0.000	0.002	0.122	0.304	0.000
PKNN	0.174	0.328	0.829	**0.012**	0.098	0.633	0.176	0.131	0.868	0.523	0.575	0.308		0.076	0.255	0.002	0.033	0.598	0.994	0.000
PKPK	**0.001**	0.425	**0.047**	0.458	**0.001**	**0.012**	0.672	0.792	0.108	**0.016**	**0.009**	0.449	0.076		0.004	0.000	0.000	0.022	0.075	0.000
PKWL	0.962	**0.035**	0.356	**0.000**	0.602	0.402	**0.013**	**0.008**	0.192	0.617	0.451	**0.032**	0.255	**0.004**		0.063	0.314	0.541	0.258	0.012
WL	**0.027**	**0.000**	**0.004**	**0.000**	0.206	**0.001**	**0.000**	**0.000**	**0.001**	**0.015**	**0.001**	**0.000**	**0.002**	**0.000**	0.063		0.480	0.011	0.002	0.294
WLLB	0.265	**0.002**	0.054	**0.000**	0.627	**0.046**	**0.001**	**0.000**	**0.021**	0.133	0.056	**0.002**	**0.033**	**0.000**	0.314	0.480		0.107	0.033	0.129
WLNN	0.451	0.133	0.755	**0.003**	0.258	0.895	0.061	**0.042**	0.487	0.911	0.962	0.122	0.598	**0.022**	0.541	**0.011**	0.107		0.602	0.002
WLPK	0.176	0.324	0.835	**0.012**	0.099	0.639	0.174	0.129	0.862	0.527	0.580	0.304	0.994	0.075	0.258	**0.002**	**0.033**	0.602		0.000
WLWL	**0.004**	**0.000**	**0.001**	**0.000**	**0.046**	**0.000**	**0.000**	**0.000**	**0.000**	**0.003**	**0.000**	**0.000**	**0.000**	**0.000**	**0.012**	0.294	0.129	**0.002**	**0.000**	

APPENDIX G: MULTIPLE COMPARISONS OF EGG WEIGHT (G) DIFFERENCE BETWEEN THE CHICKEN BREEDS PERFORMED BY LSD POST HOC TEST

	LBLB	LBNN	LBPK	LBWL	NNLB	NNNN	NNPK	NNWL	PKLB	PKNN	PKPK	PKWL	WLLB	WLNN	WLPK	WLWL
LBLB		0.032	0.679	0.068	0.435	0.075	0.169	0.025	0.748	0.614	0.010	0.963	0.890	0.927	0.748	0.748
LBNN	**0.032**		0.082	0.000	0.169	0.000	0.001	0.927	0.014	0.008	0.000	0.029	0045	0.025	0.068	0.068
LBPK	0.679	0.082		0.025	0.713	0.029	0.075	0.068	0.463	0.359	0.003	0.646	0.783	0.614	0.927	0.927
LBWL	0.068	**0.000**	**0.025**		0.010	0.963	0.646	0.000	0.131	0.184	0.435	0.075	0.050	0.082	0.032	0.032
NNLB	0.435	0.169	0.713	**0.010**		0.011	0.032	0.143	0.271	0.200	0.001	0.409	0.521	0.383	0.646	0.646
NNNN	0.075	**0.000**	**0.029**	0.963	**0.011**		0.679	0.000	0.143	0.200	0.409	0.082	0.055	0.091	0.036	0.,036
NNPK	0.169	**0.001**	0.075	0.646	**0.032**	0.679		0.000	0.292	0.383	0.216	0.184	0.131	0.200	0.091	0.091
NNWL	**0.025**	0.927	0.068	**0.000**	0.143	**0.000**	**0.000**		0.011	0.006	0.000	0.023	0.036	0.020	0.055	0.055
PKLB	0.748	**0.014**	0.463	0.131	0.271	0.143	0.292	**0.011**		0.854	0.023	0.783	0.646	0.818	0.521	0.521
PKNN	0.614	**0.008**	0.359	0.184	0.200	0.200	0.383	**0.006**	0.854		0.036	0.646	0.521	0.679	0.409	0.409
PKPK	**0.010**	**0.000**	**0.003**	0.435	**0.001**	0.409	0.216	**0.000**	**0.023**	**0.036**		0.011	0.006	0.012	0.004	0.004
PKWL	0.963	**0.029**	0.646	0.075	0.409	0.082	0.184	**0.023**	0.783	0.646	**0.011**		0.854	0.963	0.713	0.713
WLLB	0.890	**0.045**	0.783	**0.050**	0.521	0.055	0.131	**0.036**	0.646	0.521	**0.006**	0.854		0.818	0.854	0.854
WLNN	0.927	**0.025**	0.614	0.082	0.383	0.091	0.200	**0.020**	0.818	0.679	**0.012**	0.963	0.818		0.679	0.679
WLPK	0.748	0.068	0.927	**0.032**	0.646	**0.036**	0.091	**0.055**	0.521	0.409	**0.004**	0.713	0.854	0.679		1.000
WLWL	0.748	0.068	0.927	**0.032**	0.646	**0.036**	0.091	**0.055**	0.521	0.409	**0.004**	0.713	0.854	0.679	1.000	

APPENDIX H: MULTIPLE COMPARISONS OF EGG LENGTH CIRCUMFERENCE (MM) MEAN BETWEEN THE CHICKEN BREEDS PERFORMED BY LSD POST HOC TEST

	LBLB	**LBNN**	**LBPK**	**LBWL**	**NNLB**	**NNNN**	**NNPK**	**NNWL**	**PKLB**	**PKNN**	**PKPK**	**PKWL**	**WLLB**	**WLNN**	**WLPK**	**WLWL**
LBLB		0.122	0.925	0.851	0.280	0.065	0.676	0.146	0.742	0.778	0.166	0.672	0.260	0.925	0.505	0.324
LBNN	0.122		0.146	0.174	0.638	0.001	0.050	0.925	0.222	0.068	0.004	0.260	0.672	0.101	0.377	0.573
LBPK	0.925	0.146		0.925	0.324	0.052	0.608	0.174	0.814	0.707	0.140	0.742	0.302	0.851	0.566	0.372
LBWL	0.851	0.174	0.925		0.372	0.042	0.544	0.205	0.888	0.638	0.116	0.814	0.348	0.778	0.632	0.424
NNLB	0.280	0.638	0.324	0.372		0.004	0.135	0.707	0.452	0.174	0.014	0.511	0.962	0.241	0.679	0.925
NNNN	0.065	**0.001**	**0.052**	**0.042**	**0.004**		0.151	0.001	0.030	0.116	0.638	0.024	0.003	0.079	0.012	0.005
NNPK	0.676	**0.050**	0.608	0.544	0.135	0.151		0.062	0.455	0.892	0.333	0.400	0.123	0.746	0.278	0.161
NNWL	0.146	0.925	0.174	0.205	0.707	**0.001**	0.062		0.260	0.083	0.005	0.302	0.742	0.122	0.430	0.638
PKLB	0.742	0.222	0.814	0.888	0.452	**0.030**	0.455	0.260		0.541	0.087	0.925	0.424	0.672	0.735	0.511
PKNN	0.778	0.068	0.707	0.638	0.174	0.116	0.892	0.083	0.541		0.270	0.481	0.159	0.851	0.343	0.205
PKPK	0.166	**0.004**	0.140	0.116	**0.014**	0.638	0.333	**0.005**	0.087	0.270		0.071	0.013	0.197	0.041	0.018
PKWL	0.672	0.260	0.742	0.814	0.511	**0.024**	0.400	0.302	0.925	0.481	0.071		0.481	0.605	0.807	0.573
WLLB	0.260	0.,672	0.302	0.348	0.962	**0.003**	0.123	0.742	0.424	0.159	**0.013**	0.481		0.222	0.645	0.888
WLNN	0.925	0.101	0.851	0.778	0.241	0.079	0.746	0.122	0.672	0.851	0.197	0.605	0.222		0.447	0.280
WLPK	0.505	0.377	0.,566	0.632	0.679	**0.012**	0.278	0.430	0.735	0.343	**0.041**	0.807	0.645	0.447		0.749
WLWL	0.324	0.573	0.372	0.424	0.925	**0.005**	0.161	0.638	0.511	0.205	**0.018**	0.573	0.888	0.280	0.749	

APPENDIX I: MULTIPLE COMPARISONS OF EGG YOLK WEIGHT (G) MEAN BETWEEN THE CHICKEN PERFORMED BY LSD POST HOC TEST

	LBLB	**LBNN**	**LBPK**	**LBWL**	**NNLB**	**NNNN**	**NNPK**	**NNWL**	**PKLB**	**PKNN**	**PKPK**	**PKWL**	**WLLB**	**WLNN**	**WLPK**	**WLWL**
LBLB		0.029	0,306	0.144	0.080	0.380	0.464	0.000	0.004	0.014	0.108	0.041	0.001	0.000	0.000	0.020
LBNN	**0.029**		0,001	0.000	0.660	0.188	0.004	0.004	0.464	0.770	0.558	0.884	0.306	0.004	0.108	0.884
LBPK	0.306	**0.001**		0.660	0.006	0.058	0.770	0.000	0.000	0.001	0.009	0.002	0.000	0.000	0.000	0.001
LBWL	0.144	**0.000**	0.660		0.001	0.020	0.464	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000
NNLB	0.080	0.660	**0.006**	**0.001**		0.380	0.014	0.001	0.242	0.464	0.884	0.770	0.144	0.001	0.041	0.558
NNNN	0.380	0.188	**0.058**	**0.020**	0.380		0.108	0.000	0.041	0.108	0.464	0.242	0.020	0.000	0.004	0.144
NNPK	0.464	**0.004**	0.770	0.464	**0.014**	0.108		0.000	0.000	0.001	0.020	0.006	0.000	0.000	0.000	0.002
NNWL	**0.000**	**0.004**	**0.000**	**0.000**	**0.001**	**0.000**	**0.000**		0.029	0.009	0.001	0.002	0.058	1.000	0.188	0.006
PKLB	**0.004**	0.464	**0.000**	**0.000**	0.242	**0.041**	**0.000**	**0.029**		0.660	0.188	0.380	0.770	0.029	0.380	0.558
PKNN	**0.014**	0.770	**0.001**	**0.000**	0.464	0.108	**0.001**	**0.009**	0.660		0.380	0.660	0.464	0.009	0.188	0.884
PKPK	**0.108**	0.558	**0.009**	**0.002**	0.884	0.464	**0.020**	**0.001**	0.188	0.380		0.660	0.108	0.001	0.029	0.464
PKWL	**0.041**	0.884	**0.002**	**0.001**	0.770	0.242	**0.006**	**0.002**	0.380	0.660	0.660		0.242	0.002	0.080	0.770
WLLB	**0.001**	0.306	**0.000**	**0.000**	0.144	**0.020**	**0.000**	**0.058**	0.770	0.464	0.108	0.242		0.058	0.558	0.380
WLNN	**0.000**	**0.004**	**0.000**	**0.000**	**0.001**	**0.000**	**0.000**	1.000	**0.029**	**0.009**	**0.001**	**0.002**	**0.058**		0.188	0.006
WLPK	**0.000**	0.108	**0.000**	**0.000**	**0.041**	**0.004**	**0.000**	0.188	0.380	0.188	**0.029**	0.080	0.558	0.188		
WLWL	**0.020**	0.884	**0.001**	**0.000**	0.558	0.144	**0.002**	**0.006**	0.558	0.884	0.464	0.770	0.380	**0.006**	0,144	

APPENDIX J: MULTIPLE COMPARISONS PERFORM BY LSD POST HOC TEST ON EGG YOLK HEIGHT (MM) BETWEEN THE CHICKEN BREEDS

	LBLB	**LBNN**	**LBPK**	**LBWL**	**NNLB**	**NNNN**	**NNPK**	**NNWL**	**PKLB**	**PKNN**	**PKPK**	**PKWL**	**WLLB**	**WLNN**	**WLPK**	**WLWL**
LBLB		0.039	0.925	0.450	0.049	0.012	0.008	0.031	0.980	0.559	0.422	0.947	0.708	0.090	0.001	0.000
LBNN	**0.039**		0.031	0.186	0.918	0.654	0.537	0.927	0.041	0.136	0.004	0.033	0.089	0.000	0.000	0.000
LBPK	0.925	**0.031**		0.396	0.039	0.009	0.006	0.024	0.906	0.498	0.478	0.978	0.639	0.109	0.001	0.000
LBWL	0.450	0.186	0.396		0.222	0.077	0.053	0.157	0.465	0.864	0.120	0.411	0.703	0.015	0.000	0.000
NNLB	**0.049**	0.918	**0.039**	0.222		0.582	0.472	0.846	0.052	0.164	0.006	0.042	0.110	0.000	0.000	0.000
NNNN	**0.012**	0.654	**0.009**	0.077	0.582		0.866	0.722	0.013	0.053	0.001	0.010	0.032	0.000	0.000	0.000
NNPK	**0.008**	0.537	**0.006**	**0.053**	0.472	0.866		0.599	0.008	0.036	0.001	0.006	0.021	0.000	0.000	0.000
NNWL	**0.031**	0.927	**0.024**	0.157	0.846	0.722	0.599		0.033	0.113	0.003	0.026	0.073	0.000	0.000	0.000
PKLB	0.980	**0.041**	0.906	0.465	**0.052**	**0.013**	**0.008**	**0.033**		0.576	0.408	0.927	0.726	0.085	0.001	0.000
PKNN	0.559	0.136	0.498	0.864	0.164	**0.053**	**0.036**	0.113	0.576		0.166	0.515	0.834	0.023	0.000	0.000
PKPK	0.422	**0.004**	0.478	0.120	**0.006**	**0.001**	**0.001**	**0.003**	0.408	0.166		0.461	0.239	0.369	0.011	0.003
PKWL	0.947	**0.033**	0.978	0.411	**0.042**	**0.010**	**0.006**	**0.026**	0.927	0.515	0.461		0.659	0.103	0.001	0.000
WLLB	0.708	0.089	0.639	0.703	0.110	**0.032**	**0.021**	0.073	0.726	0.834	0.239	0.659		0.039	0.000	0.000
WLNN	0.090	**0.000**	0.109	**0.015**	**0.000**	**0.000**	**0.000**	**0.000**	0.085	**0.023**	0.369	0.103	**0.039**		0.096	0.037
WLPK	**0.001**	**0.000**	**0.001**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	**0.000**	**0.011**	**0.001**	**0.000**	0.096		0.670
WLWL	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.003**	**0.000**	**0.000**	**0.037**	0.670	